62-4-5

Report No. RR-49

Copy No. 16

Physical Science Laboratory
Research Division
Research and Engineering Directorate

AN ELECTROLYTIC PAINT SYSTEM

by

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Project No. 5510.1[illegible]7000

D/A Project No. 5[illegible]-001

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ABSTRACT

A practical electrolytic paint system is described and evaluated in terms of reducing atmospheric corrosion of military vehicles in storage. The system was applied on the body of a M-38-A1 test vehicle and subjected to 3-years outside exposure in the Detroit Michigan area. Comparison is made between the electrolytic method of corrosion control and conventional Ordnance exterior finishes for military motor vehicles.

Protection is achieved by impressing a small D. C. voltage thru the electrolytic paint. The vehicle body is then made cathodic with respect to an anodic conductive coating.

The theory of the electrolytic paint system is discussed and the potentials required for the protection of the test vehicle are outlined. A series of photographs illustrate the extent of corrosion occurring in the electrolytic system as well as the conventional finish.

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PROJECT TITLE: AN ELECTROLYTIC PAINT SYSTEM

OBJECTIVE:

To investigate the practical application of an electrolytic paint system for reducing atmospheric corrosion of Ordnance vehicles in storage.

INTRODUCTION:

The Electrolytic System.

Techniques of cathodic protection are well known and extensively used in industry. Underground pipe lines and tanks can be so protected as well as marine structures in salt water environments. In practice, the metal to be protected is made the cathode or negative terminal of a D. C. power source. The essential components of a cathodic system are then:

1. The Electrolyte.

2. The Cathode, or item to be protected.

3. A Sacrificial or anodic electrode.

4. D. C. power source.

Underground and submerged sea water structures are therefore easily protected by cathodic techniques since in both cases, soil or sea water act as an efficient electrolyte. Metal structures in the atmosphere, however, cannot be cathodically protected since air is a non-conductor and is not an electrolyte.

To overcome this problem, a special semi-conducting electrolytic paint was formulated to act as an electrolyte for metal structures in air environments.

Program History.

On October of 1956 a research program was initiated in the Physical Sciences Laboratory, Research & Engineering Directorate, to investigate practical mediums which could be used as electrolytes for air structures. The results of this study are described in Report 4048*.

*Application of Cathodic Protection for the Prevention of Atmospheric Corrosion, 20 Jan 1958, Detroit Arsenal Report No. 4048.

This study resulted in the formulation of a semi-conducting electrolytic paint which could be either brushed or sprayed directly on clean metal structures. A conductive metal coating applied over the electrolytic paint acted as the anode of the electrical system. In a laboratory test small metal panels were finished with the electrolytic and anodic coatings and subjected to an accelerated weathering test. Panels with cathodic protecting voltages applied through the electrolytic paint exhibited 0.224% weight loss as compared to 0.712% weight loss for conventional painted panels. This was after a 60 day exposure period.

Based on the results of these tests, a program was initiated in March of 1958 to apply the electrolytic paint system on the body of a M-38-A1 test vehicle. The vehicle would then be subjected to a 3-year outside exposure test to evaluate and compare the cathodic techniques of corrosion control with conventional Ordnance finishes.

SUMMARY:

The electrolytic-cathodic paint system was applied on body panels of a M-38-A1 test vehicle. Prior to the application of the E. C. system, the body was removed from the vehicle, disassembled, and the original paint removed down to clean base metal. To arrive at comparative results, individual body panels were selected for treatment as follows:

1. E. C. paint system with cathodic potential applied. (called System "P")

2. E. C. paint system without cathodic potential applied. (called System "N")

3. Standard Ordnance exterior finish. (called System "O")

The standard Ordnance finish consisted of a TT-P-636 red oxide primer with a finish coat of TT-E-529 olive drab enamel.

Visual and photographic observations were made on the condition of the body panels during the 3-year exposure period. The extent of corrosion occurring in the E. C. system without protecting potential was measured in terms of the polarity and density of galvanic currents generated between the anode and cathode of the system.

The electrical potential applied to the various body panels (cathodes) protected with the E. C. system was maintained at minus 0.85 volts with respect to anode potential.

During the 3-year exposure period photographic and visual observations were made on body panels to indicate and compare corrosion defects.

The degree of protection afforded by the E. C. paint system can be summarized as follows for several major body components:

Body panel protected by E-C system	Observations of corrosion after 3-year exposure.
Hood, both sides	Loss of 1 electrode. No visible corrosion on inside or outside.
Left front fender, both sides	No visible corrosion on interior. No visible corrosion on exterior.
Right body panel outside only	No visible corrosion.
Dash panel, outside only	No visible corrosion over surface. Corrosion on hinge of compartment door.
Left rear fender and wheel-well (inside)	Loss of 2 electrodes. Corrosion in area of box member.

EXPERIMENTAL METHOD:

The preparation and painting of the M-38-A1* test vehicle was accomplished by the Experimental Division of the Detroit Arsenal. The vehicle was disassembled and all body members stripped of paint and other foreign material down to base metal. The chassis, power train, engine and suspension were examined for corrosion and repainted with a TT-E-529 olive drab finish coat.

Painting and Preparation Procedure.

All body members, after removal of old paint, were phosphate metal conditioned in accordance with specification MIL-P-10578, Type I.

The various body panels were then prepared as outlined in Table I.

*Odometer reading 3850 miles at time of tear down.

Ordnance Part No.	Identification	System	Notes
8328472	Hood	P	Hinges and bearing edges masked off after application of re-sistance paint. Finished with system "O".
WO-684569	Guard Assembly	N	Complete assembly painted.
7723899	Light Assembly	O	
8673513 7760504	Driving Lamp Unit	O	
WO-688234	Right Fender	O	Both sides painted.
WO-688233	Left Fender	N	System N applied to both sides of fender.
WO-684834	Front Cowl Panel	N	Outside of cowl and top side of battery cover painted with system "N". Bottom side of battery cover plate painted in acid resistant finish. All components com-pleted in system "O".
WO-680630	Body - Right Panel	P	
WO-680629	Body - Left Panel	N	Gasoline filter insert included.
	Gasoline Filler insert in left panel	O	
8332065	Windshield Assembly	O	
8677599	Instrument Panel less instrument cluster	P	Door #8329650 in-cluded. All bearing edges masked off.

TABLE I
PREPARATION AND PAINTING PROCEEDURE FOR BODY PANELS

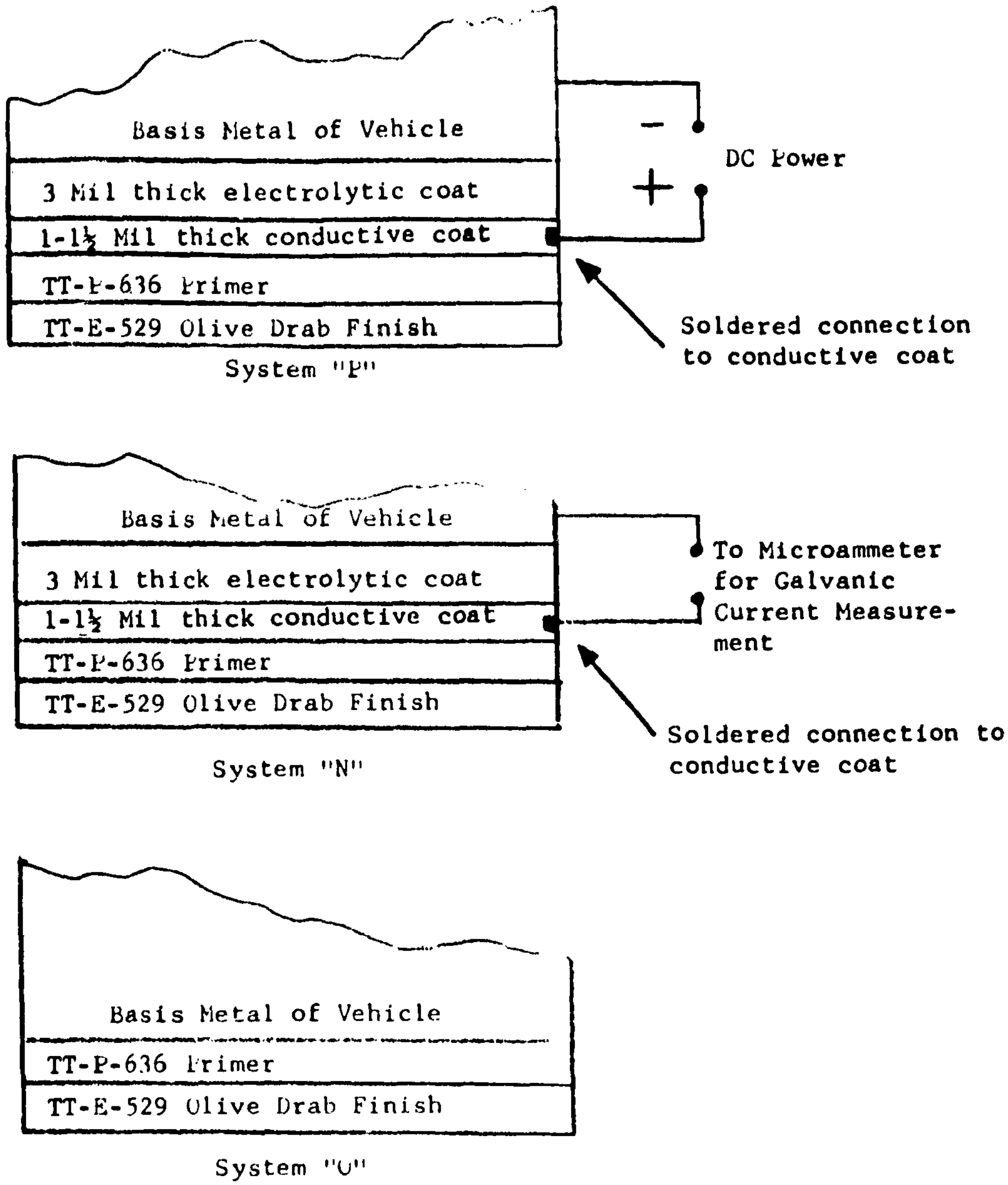
Ordnance Part No.	Identification	System	Notes
8677606	Main Floor Panel	N	Cover, No's 7697525, 7697578, included with plate WO-680506 and 7697523.
WO-680637	Rear Floor Assembly and Wheel Covers. (part of body)	P	Inside surfaces finished only.
WO-680637	Rear Vertical body panel (part of body)	O	Components, No's WO-689016, 7760506, 7760507, 7375163, 7731428 and reflectors.
7387807	Wheel Assembly		"O" system applied to 1 wheel, "N" system applied to 2 wheels, "P" system applied to 1 wheel.
	Front Bumper	O	

TABLE I (CONT'D)

PREPARATION AND PAINTING PROCEEDURE FOR BODY PANELS

The key to the paint systems P, N and O is explained in Figure 1. Paint thickness was measured with a magnetic thickness gauge. The electrolytic paint was controlled to a $\pm$ 1/2 mil thickness. To eliminate electrical "shorts" between the conductive coating and the basis metal, all bearing edges and other areas of impact were not coated with the conductive paint. This can be seen in Figure 9. Illustrated is the painting of the body. In this picture the bearing edges of the body have been masked off prior to the application of the conductive paint.

The sequence of operations relative to the preparation of the body are shown in Figures 2 thru 13.



DETAIL OF PAINT SYSTEMS P, N & O

FIGURE 1.

Figure 2 - Cleaning and Degreasing facilities.

Figure 3 - Alkali cleaning and paint removal bath.

Figure 4 - M-38-A1 body after removal of paint.

Figure 5 - Spray painting facilities.

Figure 6 - Application of electrolytic paint on body panels.

Figure 7 - Drying oven used to cure electrolytic paint.

Figure 8 - Measurement of electrolytic paint thickness.

Figure 9 - Masking of bearing edges after application of electrolytic paint.

Figure 10 - Body panel with conductive coat applied over electrolytic paint.

Figure 11 - Removal of masking tape from body after application of conductive paint.

Figure 12 - Right body panel ready for electrode attachment and final finish coat.

Figure 13 - Electrical connection with epoxy seal.

A No. 20 gauge electrical wire was affixed tothe conductive coating by means of a low temperature printed circuit solder. The soldered connection was sealed in place with an epoxy cement. The adjacent edges of various body panels finished with different paint systems were isolated one from another by a 1/8 inch strip which was sealed with an insulating paint and finished with an olive drab finish coat. This was necessary to eliminate impressed currents from one system feeding into adjacent areas of another paint system.

The chassis, engine-power train, exhaust and suspension were inspected for existing corrosion and touched up with an olive drab finish coat. Figures 14, 15 and 16 show chassis components after restoration and inspection.

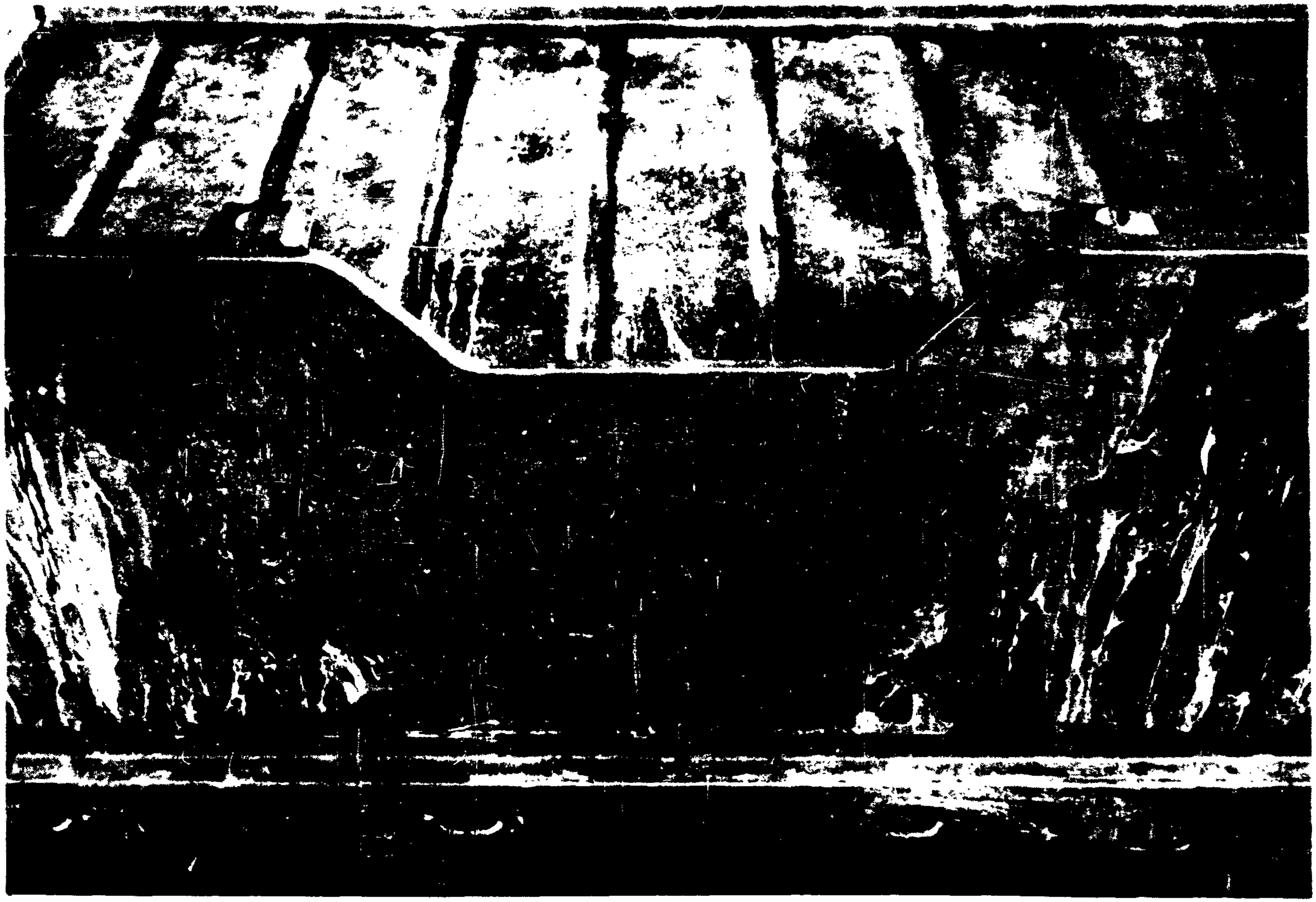
After all components were finished and inspected, the vehicle was reassembled.

CLEANING AND DEGREASING FACILITIES UTILIZED DURING COURSE OF PROJECT

FIGURE 2.

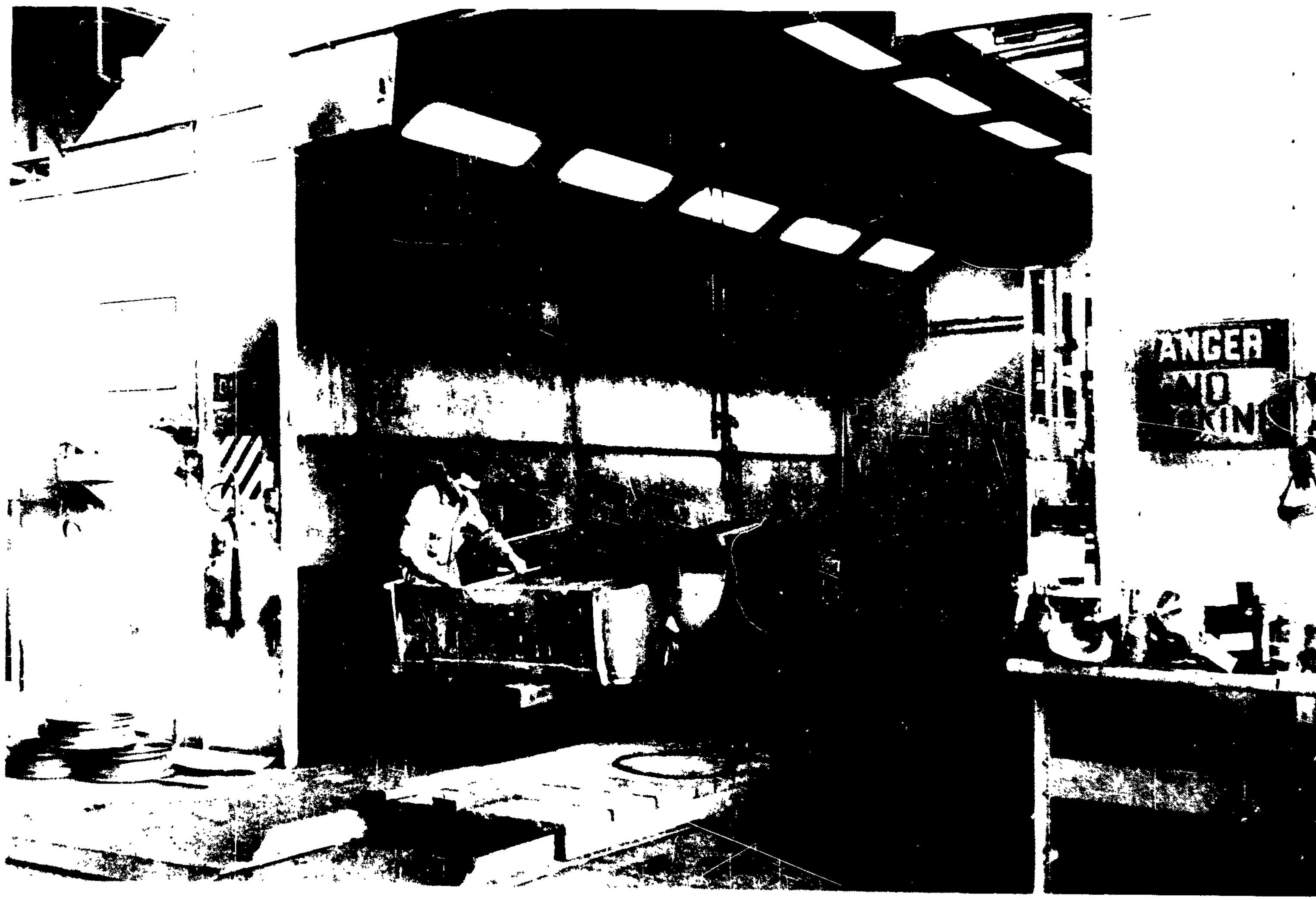
ALKALI CLEANER USED IN PAINT REMOVAL

FIGURE 3.



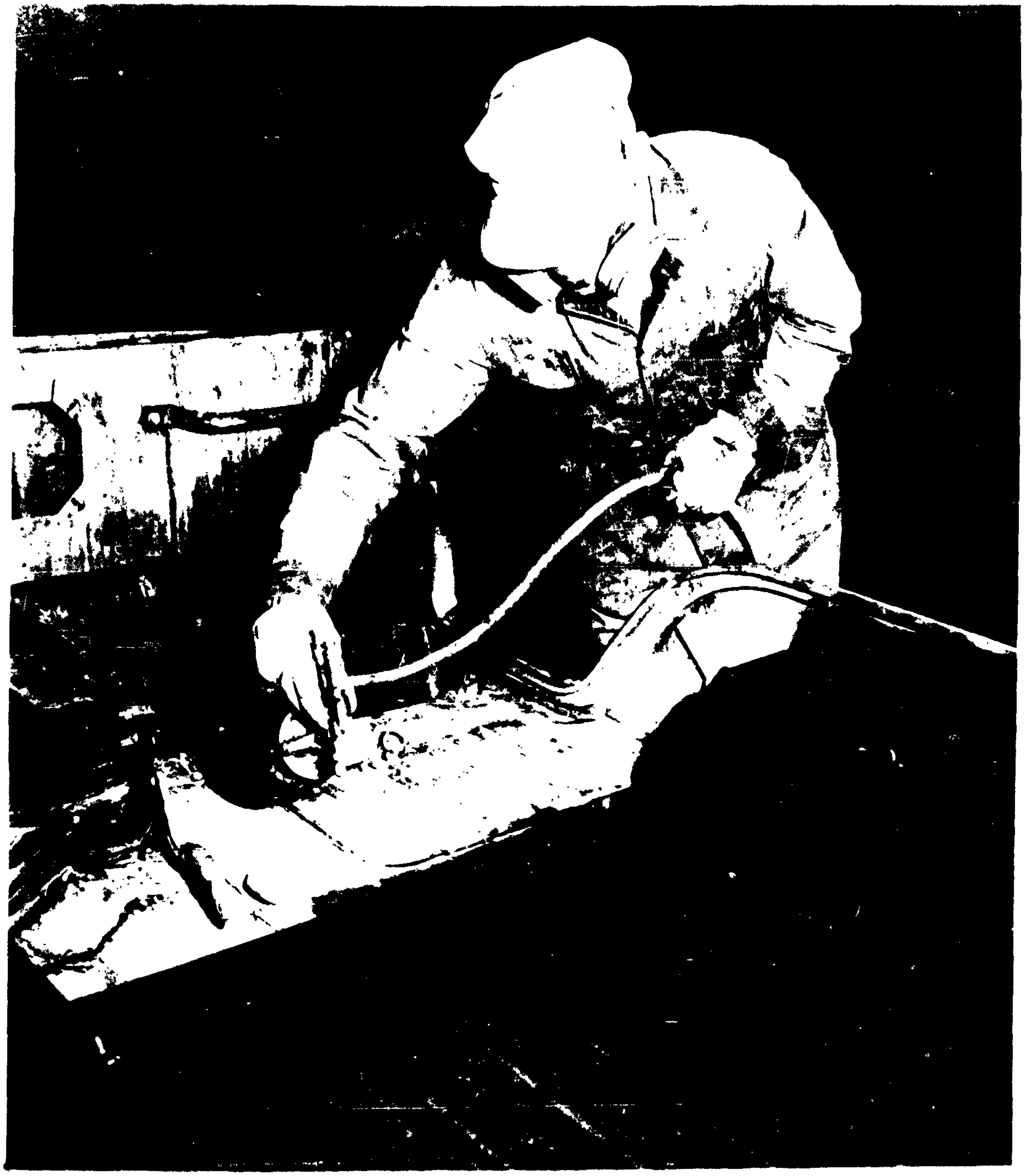
PORTION OF M-38 TEST VEHICLE BODY ILLUSTRATING CONDITION OF SURFACE AFTER REMOVAL OF OLD PAINT

FIGURE 4.



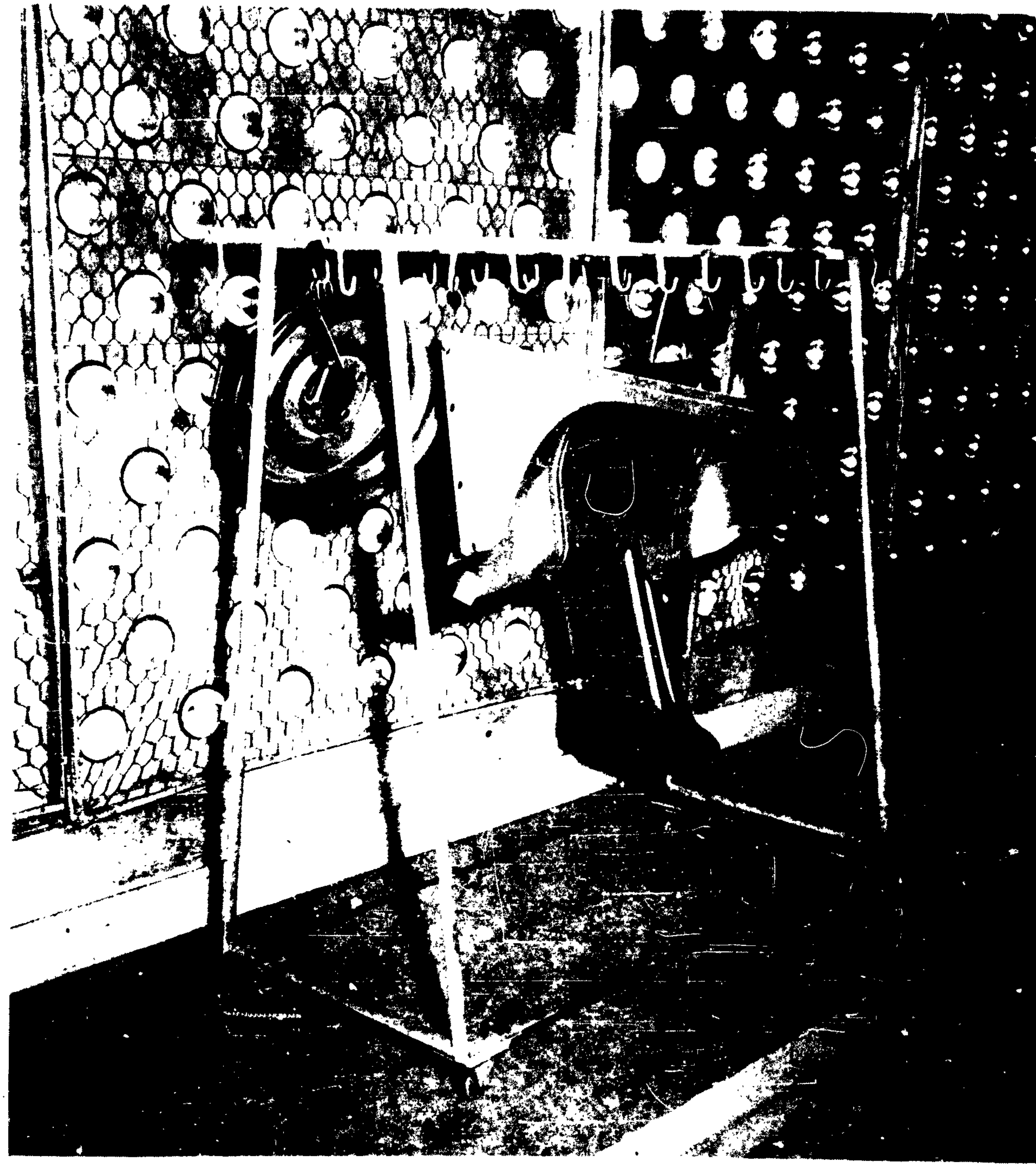
PAINTING FACILITIES UTILIZED DURING COURSE OF PROJECT

FIGURE 5.



APPLICATION OF ELECTROLYTIC PAINT ON VEHICLE BODY AREAS

FIGURE 6.



COMPONENTS OF M-38 TEST VEHICLE IN DRYING OVEN

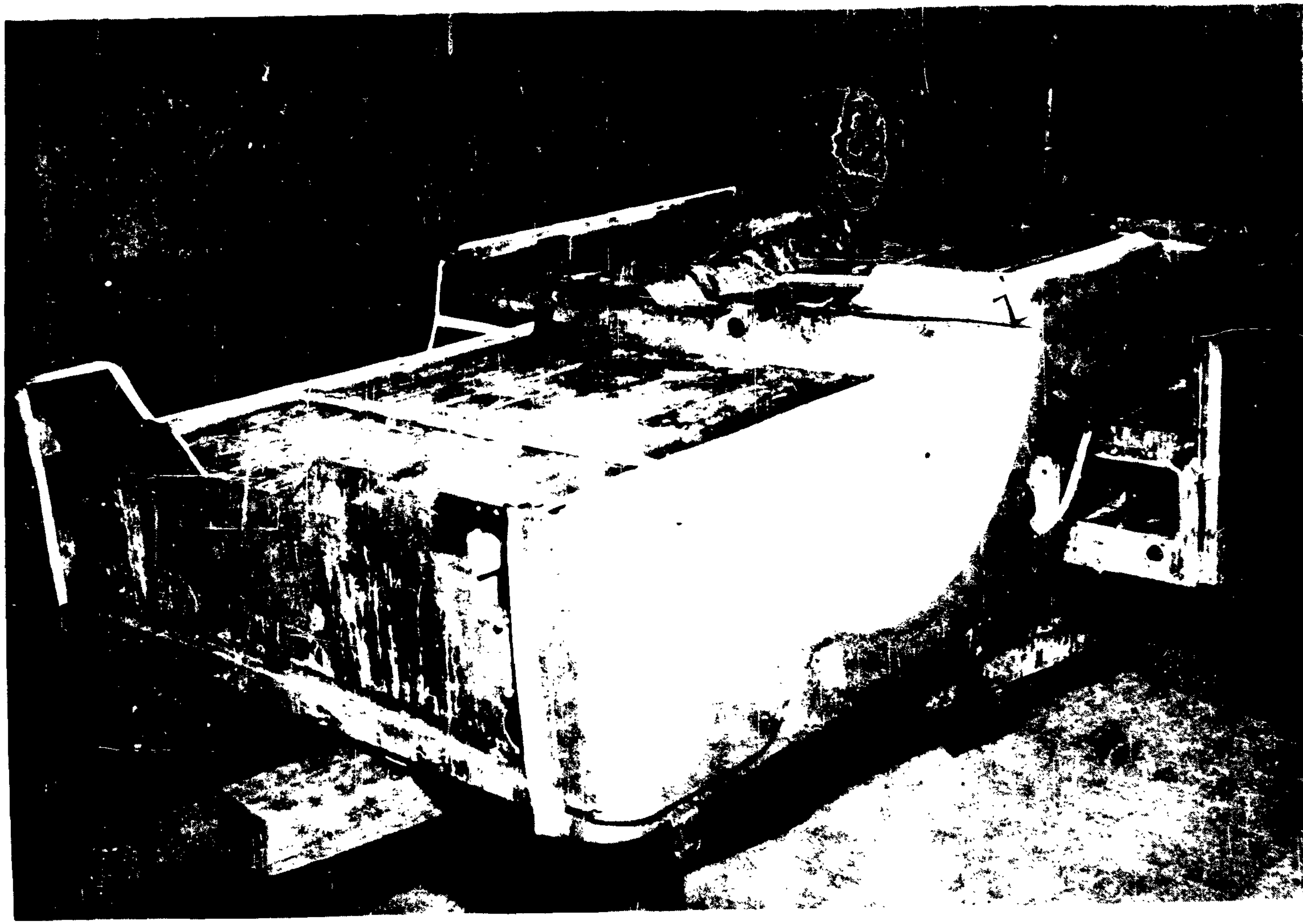
FIGURE 7.

PAINT THICKNESS MEASUREMENT OF CONDUCTIVE SURFACE, VEHICLE GRILL

FIGURE 8.

MASKING TECHNIQUE UTILIZED IN DEFINING AREAS OF PROTECTION

FIGURE 9.



BODY OF M-38 TEST VEHICLE - IN PREPARATION FOR PAINTING

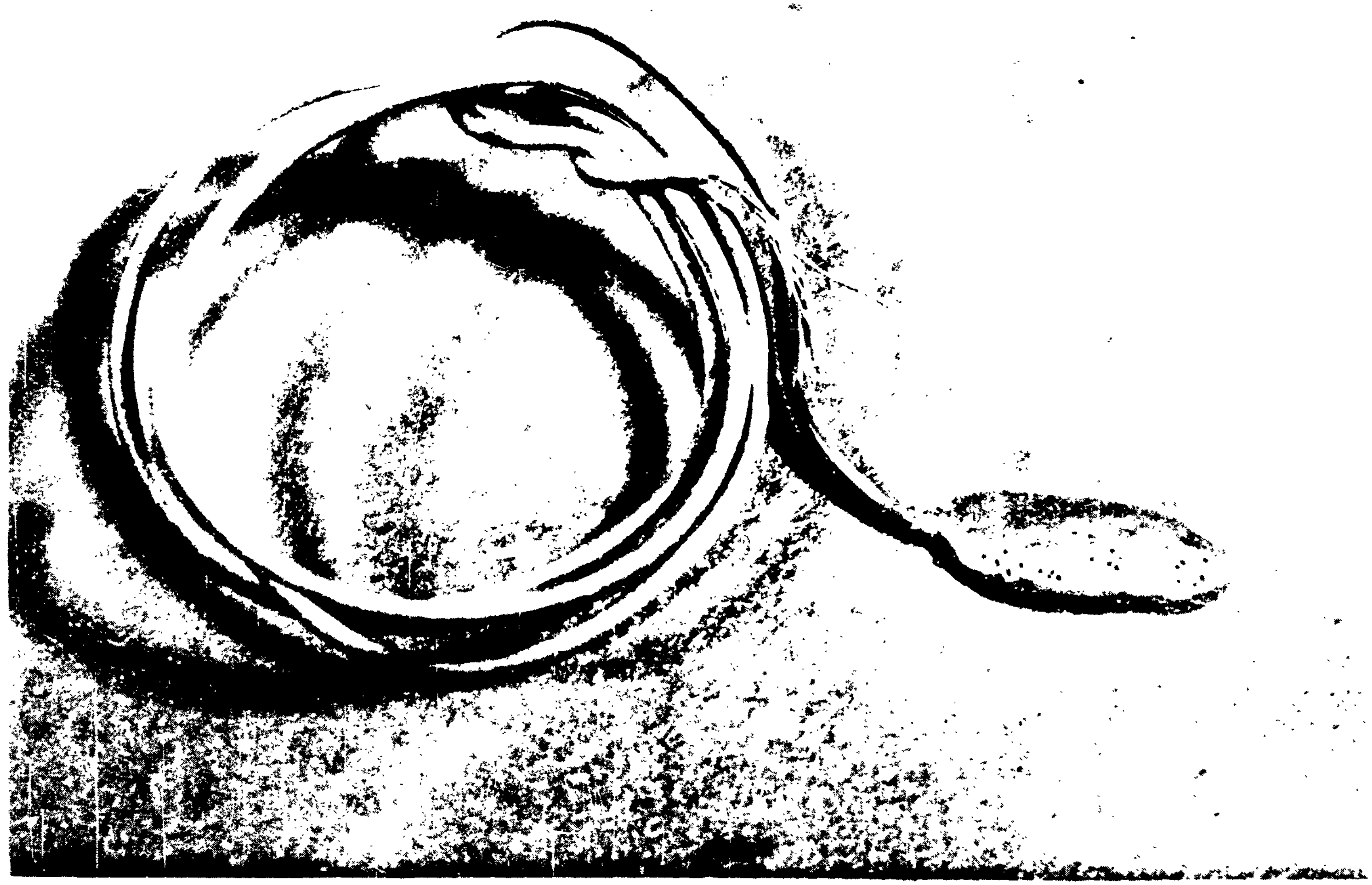
FIGURE 10.

REMOVAL OF MASKING TAPE AFTER APPLICATION OF COPPER CONDUCTING COAT

FIGURE 11.

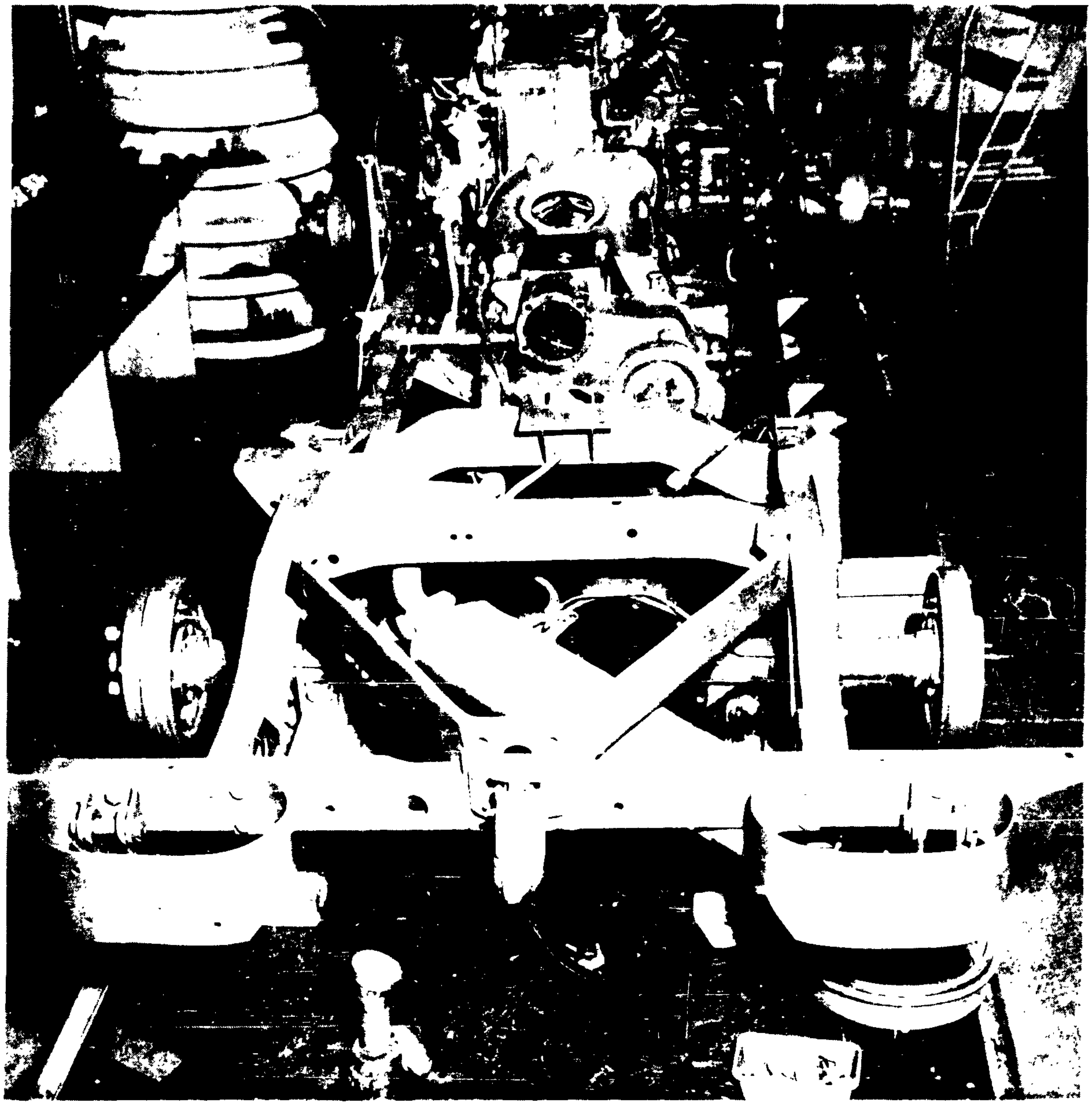
FIGURE 12.

PREPARATION OF VEHICLE BODY FOR CATHODIC PROTECTION



ELECTRICAL CONNECTION TO HOOD AFTER FINAL O. D. COAT

FIGURE 13.

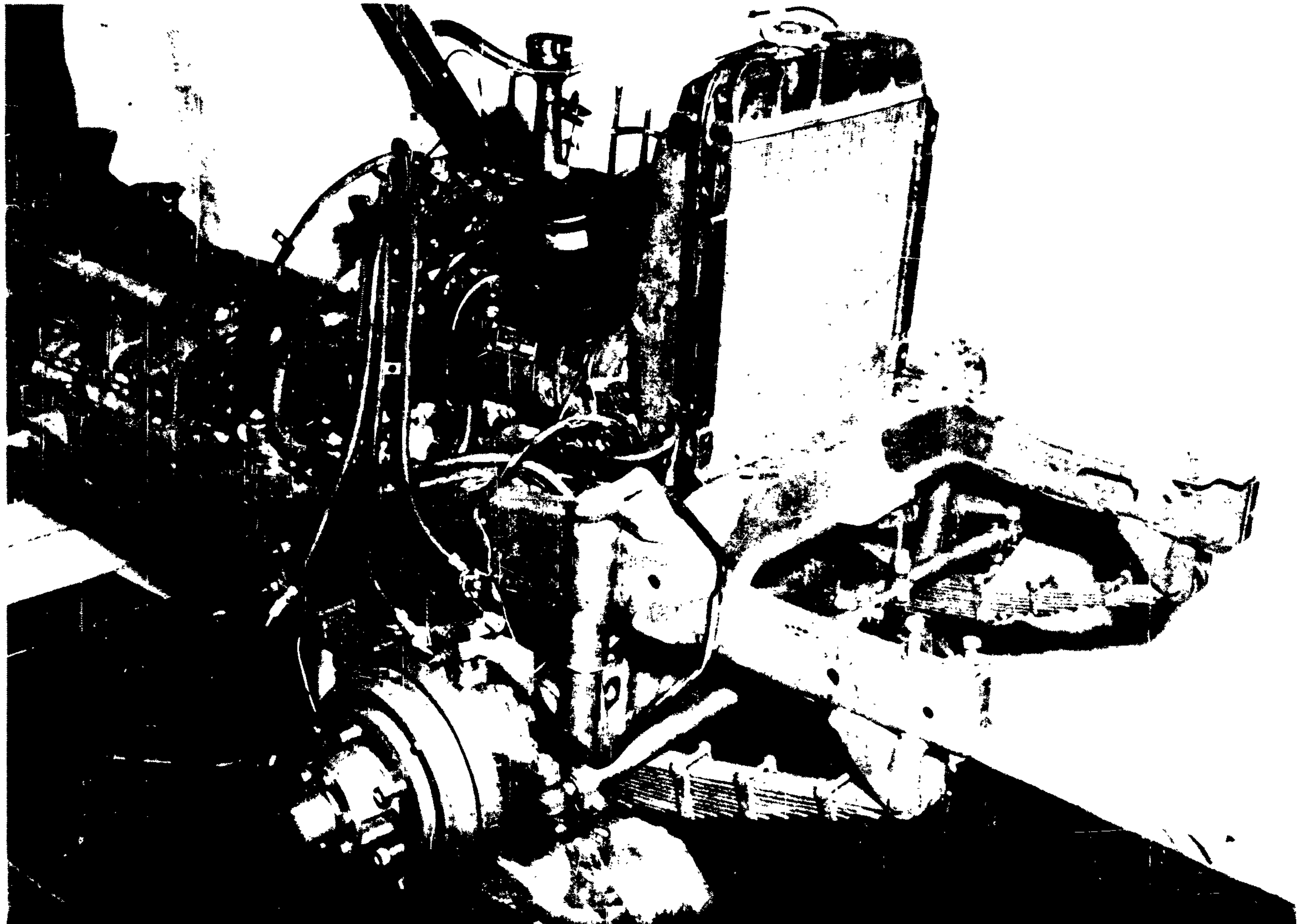


CATHODIC PROTECTION M38-A1. CHASSIS, REAR

FIGURE 14.

CATHODIC PROTECTION M38-A1. CHASSIS, RIGHT REAR

FIGURE 15.



CATHODIC PROTECTION M38-A1. CHASSIS, RIGHT FRONT

FIGURE 16.

The Test Site.

The test site for the 3-year exposure is shown in Fig. 17. The vehicle is mounted off the ground on 12" high wood stands. The vehicle faces West and is approximately 15 feet south of the laboratory building as seen in Fig. 17.

To act as a control, a spare engine, transmission, transfer assembly and rear axle were exposed with the test vehicle. The "control" components were disassembled after completion of the test and inspected. Comparison was then made between the condition of the control items and the engine-power train of the vehicle.

The electrical connections were loomed together and fed into the laboratory building where instrumentation monitored the operation of impressing the cathodic voltages to the vehicle body.

Electrical Instrumentation.

The electrical circuit used in impressing voltage on system "P" terminals is shown in Figure 18a; Figure 18b shows the circuit used in monitoring the galvanic currents generated in system "N". The termination of the circuits and power distribution board is shown in Figure 19 and 20. A D. C. power source supplied the protecting voltages for system "P".

Electrical measurements were made once a month for the first year of exposure, and quarterly thereafter. Table II identifies the 34 electrodes with respect to their use, location and resistance.

The major body components and panels protected by system "P" electrodes are listed in Table III. Also indicated are panel areas, number of electrodes per panel and panel area per electrode.

Each body panel or "block" to be protected by the electrolytic paint system had several electrodes attached to the anodic coating. In the processing of the vehicle, some electrodes were damaged and not useable. One for each block was used as a control or galvanic-electrolytic current indicator. The remaining electrodes were used to impress power into the block or items to be protected.

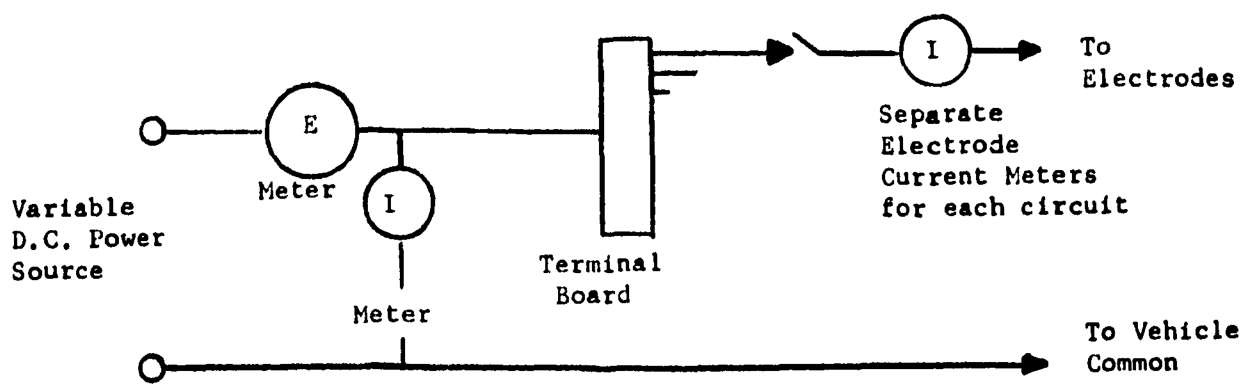


FIGURE 18a

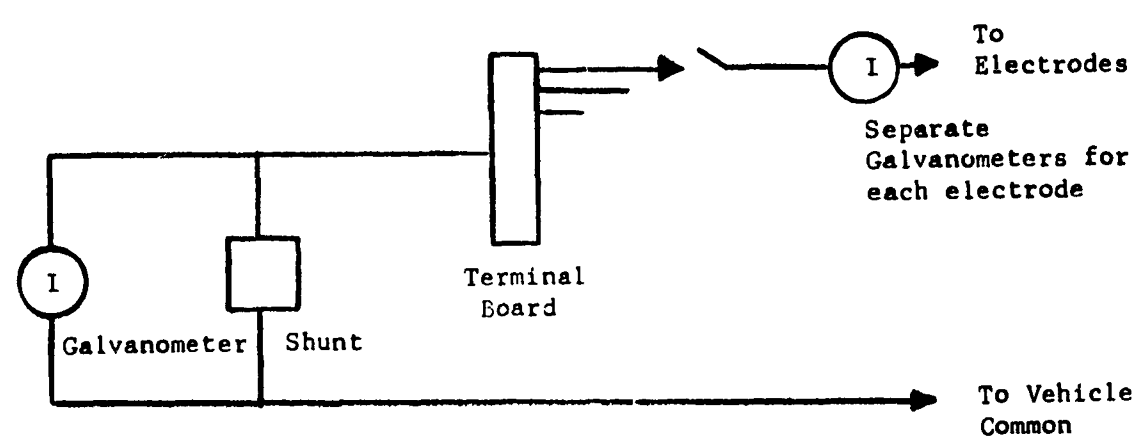
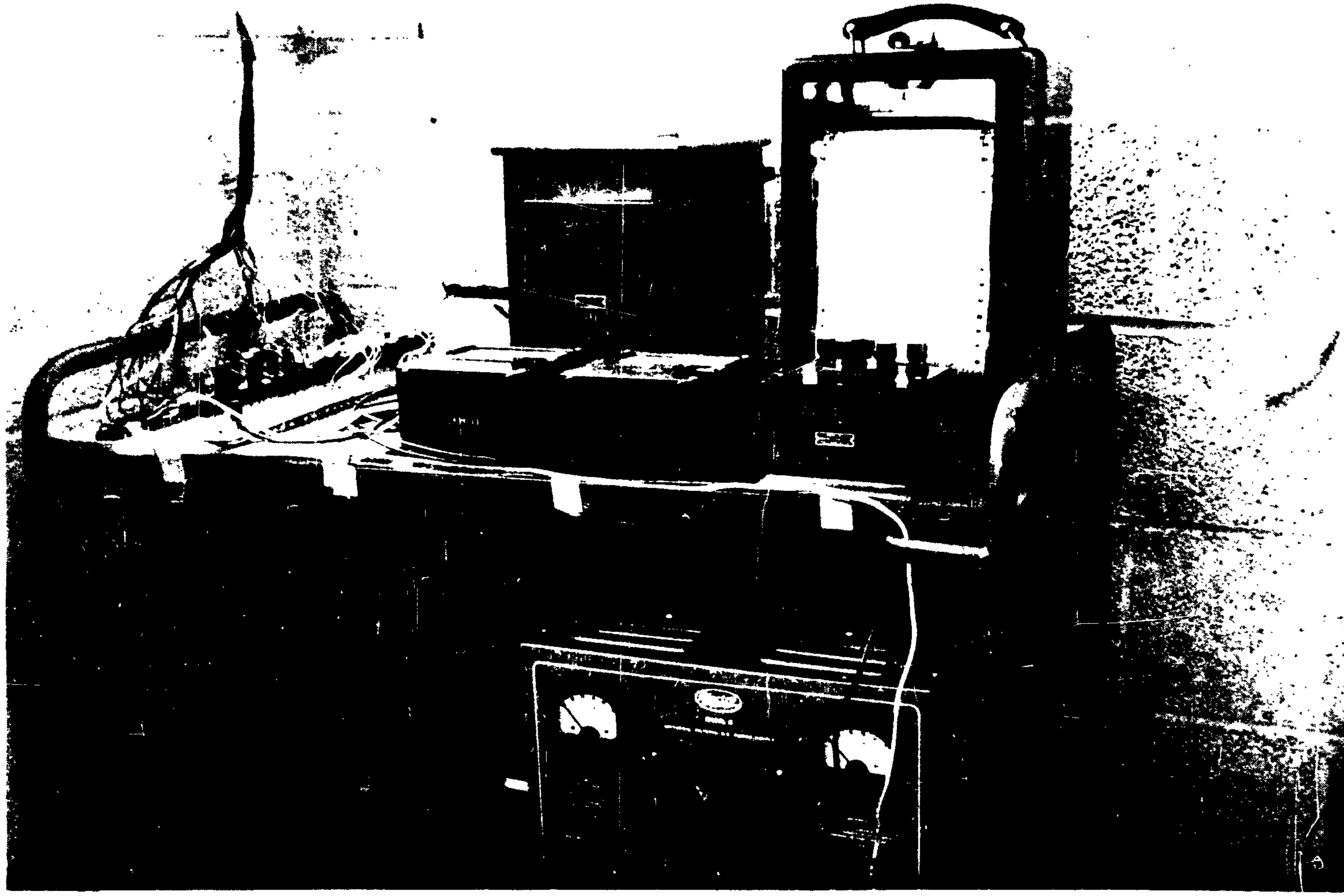


FIGURE 18b

Electrical circuits used in impressing voltage on System "P", and monitoring galvanic currents generated in System "N".

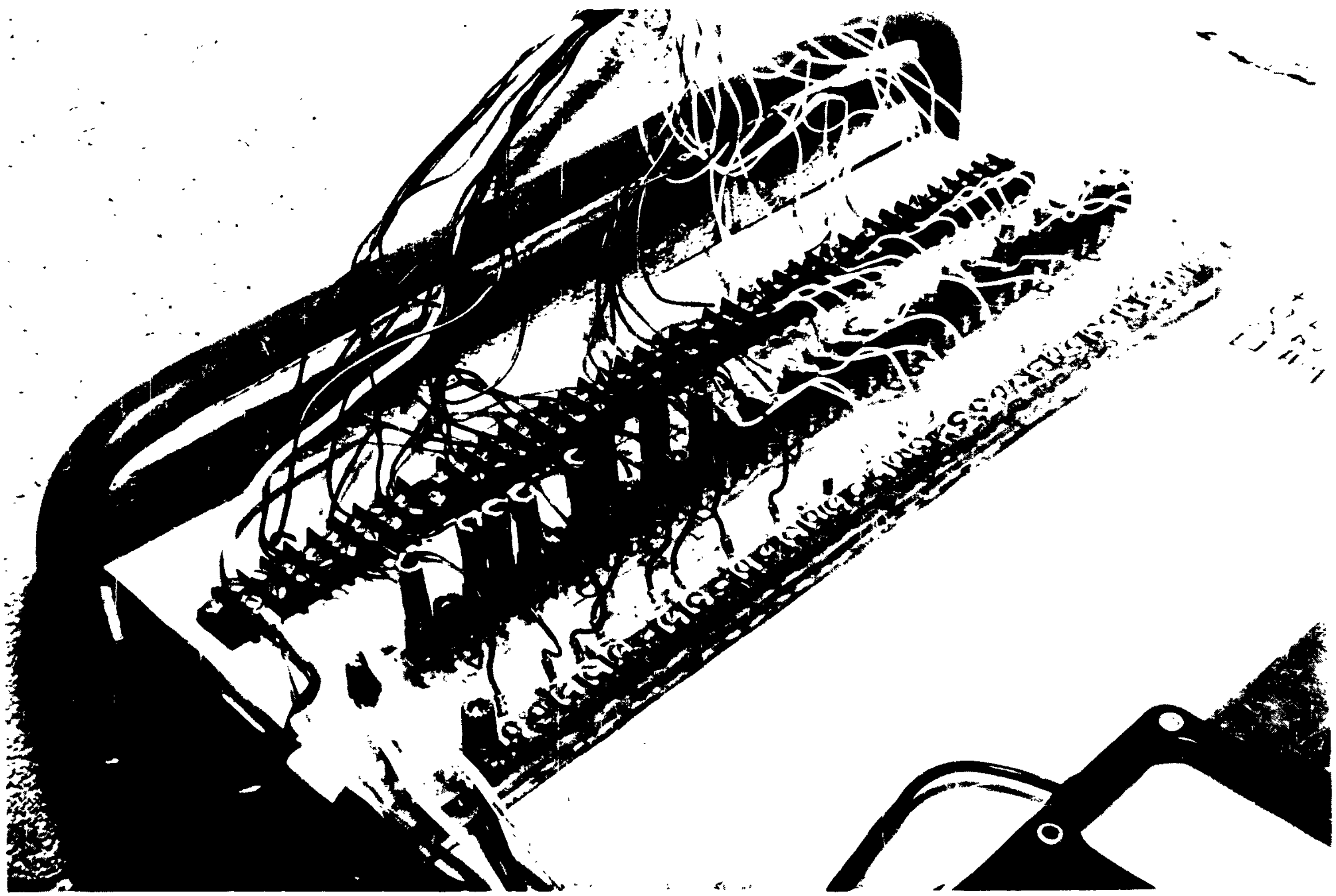
OUTSIDE EXPOSURE TEST AREA

FIGURE 17.



TEST SET -UP UTILIZED FOR DETERMINING VOLTAGE DISTRIBUTION

FIGURE 19.



TERMINAL BOARD FOR VOLTAGE DISTRIBUTION

FIGURE 20.

Terminal Number	Terminal Location	Terminal Resistance In Ohms at Start of Test	Use	Remarks
1	Hood, Top, Right Side	115	N	
2	Hood, Top, Center	150	P	
3	Hood, Top, Left Side	24	P	
4	Battery Cover	---	N	Short
5	Hood, bottom, right side	84	P	
6	Hood, bottom, Center	96	P	
7	Hood, bottom, left side	76	N	
8	Left Front, top fender	47	P	
9	Left Front, side fender	---	N	Short
10	Right Front, underside, forward fender	280	P	
11	Right, Underside, rear fender	150	P	
12	Wheel #1, outside surface	4.5	N	Thin Electro-lytic paint
13	Wheel #1, Inside surface	1.6	N	Thin Electro-lytic paint
14	Wheel #2, outside surface	4.6	N	Thin Electro-lytic paint
15	Wheel #2, inside surface	24	N	
16	Inspection plate #	43	P	
17	Inspection plate #	97	P	

TABLE II
LIST OF TEST ELECTRODES

Terminal Number	Terminal Location	Terminal Resistance In Ohms at Start of Test	Use	Remarks
18	Side body panel right-front	100	P	
19	Side body panel right-under door	165	P	
20	Side body panel, right-center	16	N	
21	Side body panel, right, over rear door	95	P	
22	Side body panel, right, far rear	80	P	
23	Dash panel, right	185	P	
24	Dash panel, center	2000	N	High resistance
25	Dash panel, left	140	P	
26	Door, compartment	740	N	
27	Rear, left, inside body fender, front	58	P	
28	Rear, left, inside body fender, back	325	P	
29	Rear, left, inside body fender, center	12	N	Low resistance
30	Rear floor panel, left-body	76	P	
31	Body, rear floor panel, right	98	P	
32	Rear, right, inside body fender, front	46	P	
33	Rear, right, inside body fender, rear	80	N	

TABLE II (CONT'D)
LIST OF TEST ELECTRODES

Terminal Number	Terminal Location	Terminal Resistance In Ohms at Start of Test	Use	Remarks
34	Rear, right, inside body fender, center	19	P	

KEY

"P" - System "P", power on electrodes

"N" - System "N", galvanic corrosion indicators

TABLE II (CONT'D)
LIST OF TEST ELECTRODES

Body Item	Terminal Number of Electrode Attached to Item	Number of Electrodes With Power "O"	Area of Item Protected, Sq. In.	Electrodes per Sq. In. of Surface to be Protected
Hood, outside	1, 2, 3	Two	1660	830
Hood, inside	5, 6, 7	Two	1660	830
Front fender, outside	8, 9	One	531	531
Front fender, inside	10, 11	Two	481	240
Right body panel	18, 19, 20, 21, 22	Four	704	176
Dash panel	23, 24, 25	Two	700	350
Left rear body Panel & Wheel Well	27, 28, 29	Two	1062	811
Right rear body Panel & Wheel Well	32, 33, 34	Two	1062	811
Body Floor	30, 31	Two	1394	697

TABLE III
SUMMARY OF MAJOR BODY COMPONENTS
PROTECTED BY SYSTEM "P"

The Electrolytic and Anodic Paints.

The electrolytic paint is a #R-41 conducting micro paint manufactured under specification by the Micro-Circuits Co. It air drys to a given electrical value in 2 hours or can be baked 10-15 minutes at 150-250F to accelerate drying.

The anodic paint is a #235 Acheson metallic copper in lacquer. It is a low loss electrical conductor having a resistance as follows:

Film Thickness	Resistance
.001 inches	6 ohms per square
.002 inches	1.5 ohms per square
.003 inches	1.0 ohms per square

COLLECTION OF DATA:

The vehicle was placed in the test area on 11 May 1959. The vehicle was removed on 19 February 1962 for a total of 33 months, 9 days exposure. During the exposure period the following electrical data was acquired.

1. Total current required to protect vehicle. (Total "P")

2. Current required by each electrode in a "P" circuit.

3. Galvanic current generated in open circuits. ("N")

In addition, photographs were taken before and during the exposure period. The engine and power train components were torn down and photographed prior to application of cathodic protecting voltages. Upon completion of the test, the engine and power train again were disassembled and inspected to see if stray electrolysis had accelerated corrosion in bearings or other critical surfaces. The extra engine and power train were used as a control for comparison with the vehicle power plant.

RESULTS:

The performance of the electrolytic-cathodic paint system is measured in terms of:

1. The degree of corrosion evidenced on E-C protected body panels.

2. Comparison with standard Ordnance finished panels.

3. Comparison with E-C paint system without protecting voltage applied.

4. Electrical operating parometers of E-C system.

The total current required to maintain a 0.85 volt potential difference between anode and cathode ranged from 340 milliamps at the start of the test to 460 milliamps after 3 years. This is plotted graphically in Figure 21. Similarily, a summary of the maximum, minimum, and average current required by the individual electrodes in the E-C system is tabulated in Table IV.

Terminal Number	Body Part	Minimum Current IN Milliamps	Maximum Current IN Milliamps	Average 3 year Current IN Milliamps	Average Current density per Sq. In. of surface area Milliamps
2	Hood, out	7.0	30.0	19.8	0.0712
3	Hood, out	4.4	130.2	98.5	0.0712
5	Hood, In	8.5	74.7	51.7	0.0495
6	Hood, In	6.4	42.0	30.5	0.0495
8	Front fender, out	2.5	30.0	9.5	0.0179
10	Front fender, inside	2.3	13.0	5.8	0.0324
11	Front fender, inside	4.5	13.0	9.8	0.0324
18	Right body panel	7.6	12.9	10.7	0.0352
19	Right body panel	1.6	7.8	2.7	0.0352
21	Right body panel	2.9	10.0	5.8	0.0352
22	Right body panel	1.5	13.8	5.6	0.0352
23	Dash panel	2.1	7.8	3.3	0.00957
25	Dash panel	1.8	5.0	3.4	0.00957
27	Left body panel and wheel well	1.4	35.0	16.2	0.0177

TABLE IV
SUMMARY OF ELECTRICAL OPERATING PARAMETERS

Terminal Number	Body Part	Minimum Current IN Milliamps	Maximum Current IN Milliamps	Average 3 year Current IN Milliamps	Average Current density per Sq. In. of Surface area Milliamps
28	Left body panel and wheel well	--	4.5	2.7	0.0177
30	Right body panel and wheel well	--	12.5	4.7	0.0125
31	Right body panel and wheel well	3.9	16.8	8.6	0.0125
32	Rear body floor	3.2	32.0	15.4	0.0347
34	Rear body floor	20.5	40.2	33.0	0.0347

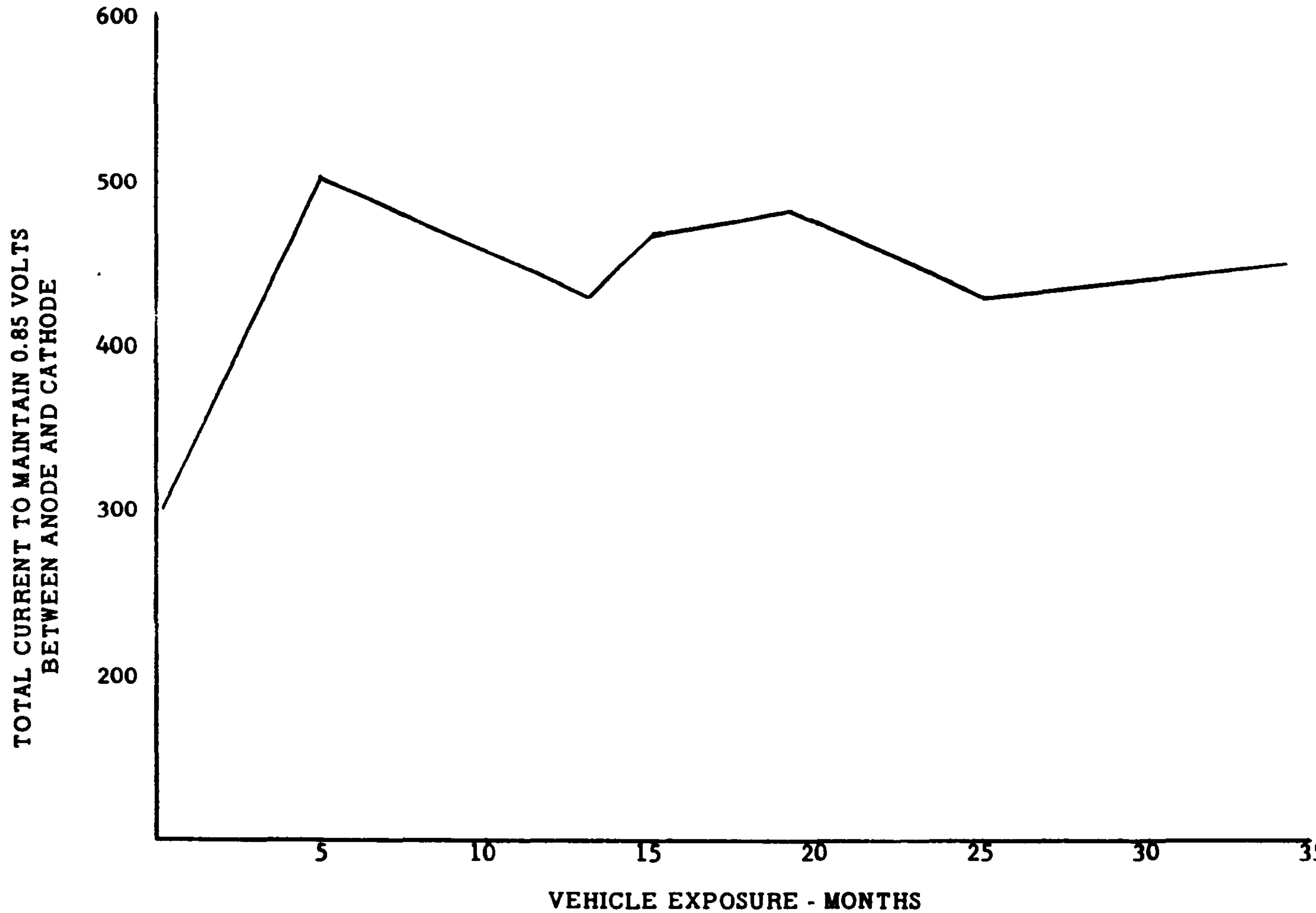
TABLE IV (CONT'D)
SUMMARY OF ELECTRICAL OPERATING PARAMETERS

Table IV summarizes and averages the electrical operating parameters for "P" circuits during the 3 year exposure period.

The galvanic currents generated in the E-C circuits without impressed voltage are summarized in Table V. These "control" circuits are used to monitor the degree of corrosive action between the anode and cathode of the particular body panel they are affixed to.

Terminal Number	Body Part	Average generated galvanic current during 3 year period	Galvanic current density
		Microamps	Microamps/sq. in.
4	Battery cover	0.0134	0.000086
12	Wheel	0.00844	0.000013
26	Door, compartment	0.001	0.000015
33	Interior body panel	0.036	0.00006

TABLE V
GALVANIC CURRENT GENERATED IN FOUR VEHICLE - BODY COMPONENTS



TOTAL CURRENT REQUIRED TO PROTECT VEHICLE DURING TEST PERIOD

FIGURE 21

Observations of Body Panel Corrosion.

The general condition of the vehicle at the start of the exposure is shown in Figures 22 thru 24. Two common defects as a result of the assembly were: (1) chipped paint (Fig. 25) and, (2) paint abraded off nuts and bolts (Fig. 26).

After 3 months exposure, corrosion was noted on the front pintel and in the area of the hood latch. Paint stains were also visible in certain areas which collected and held rain water.

3 Months

Fig 27 - Corrosion on front pintel. Paint system O

Fig 28 - Corrosion spreading from paint chip on hood latch. Paint system P

Fig 29 - Paint stain caused from run-off water. Paint system O

After 6 months exposure, corrosion had progressed in the several areas previously noted. Additional staining from run-off water also continued.

6 Months

Fig 30 - Continued corrosion on pintel. Paint system O

Fig 31 - Corrosion in area of bolt heads. Paint system O

Fig 32 - Corrosion in area of bolt heads. Paint system O

Fig 33 - White corrosion stains on grille. Paint system N

Fig 34 - Expansion of corrosion around paint chip. Paint System N

Fig 35 - Stain on paint under left head lamp. Paint system O

Fig 36 - Stain on paint under right head lamp. Paint system O

After 12 months weathering, the first paint failure was evidenced by visible red oxide corrosion. General overall chalking and discoloration of paint was also first noticed.

12 Months

Fig 37 - Corrosion along seam of battery cover plate. Paint System N

Fig 38 - Corrosion under right headlamp (loss of paint adhesion). Paint System O

Fig 39 - Lifting of electrode on hood. Paint System P

Fig 40 - Corrosion along seam of box member, left rear wheel well. Paint System N

Corrosion in the area of the lifting pintel and around bolts also progressed as shown in Figures 41 & 42.

12 Months Progressive Corrosion

Fig 41 - Progress of corrosion on pintel. Paint System O

Fig 42 - Corrosion around bolt heads of lamp bracket. Paint System O

After 25 months exposure, the general overall condition of the vehicle is shown in Figures 43 and 44. Progress of corrosion is illustrated in Figures 45 thru 49.

25 Months Progressive Corrosion

Fig 45 - Continued corrosion under right light assembly. Paint System O

Fig 46 - Loss of adhesion of paint on bearing edge (masked portion). Paint System N

Fig 47 - Continued lifting of electrode on hood. Paint System O

Fig 48 - Loss of adhesion of electrode on right wheel well. Paint System P

Fig 49 - Loss of adhesion of paint on battery cover. Paint System N

Final photographic observations were made at 34 months.

34 Months Progressive Corrosion

Fig 50 - Corrosion on battery cover. Paint System N

Fig 51 - Corrosion under right head lamp assembly. Paint System O

Fig 52 - Corrosion under left headlamp assembly. Paint System O

Fig 53 - Loss of electrode on hood, Paint System P

Fig 54 - Corrosion along seam of left rear body panel. Paint System N

Fig 55 - Corrosion in area of grille. Paint System N

Fig 56 - Corrosion on left front fender. Paint System N

Fig 57 - Corrosion on hinge of panel door. Paint System P

Fig 58 - Corrosion on windshield hindge. Paint System O

Fig 59 - Corrosion in area of hood latch. Paint System O

The condition of the rear interior floor and wheel well panels is shown in Figure 60. Corrosion is visible along seam structures on the floor. These panels have been painted with System P.

The general outside condition of the vehicle after it was removed from the test blocks and put into operation is shown in Figures 61 thru 64.

Observations of Engine Power Train Corrosion

The engine power train and mechanical components of the test vehicle were photographed prior to exposure and again upon completion of the 35 months outside weathering course.

Photographs of mechanical components prior to exposure are shown in Figures 65 thru 67. The same components after exposure are again shown in Figures 68 thru 70.

Before Exposure	After 35 Months Exposure	Component
Fig 65	Fig 68	Front Differential & Springs
Fig 66	Fig 69	Wheel Ball Joint
Fig 67	Fig 70	Muffler

The internal condition of the engine before and after 35 months exposure is shown in Figures 73 thru 80.

Vehicle Engine Before Exposure	Vehicle Engine after 35 Months Exposure	Component
Fig. 73	Fig. 76	Rocker Arms & Valve Cover
Fig. 74	Fig. 77	Head
Fig. 75	Fig. 78	Cylinder Walls
	Fig. 79	Cylinder Walls
	Fig. 80	Crankshaft

Paint Chalking & Fading

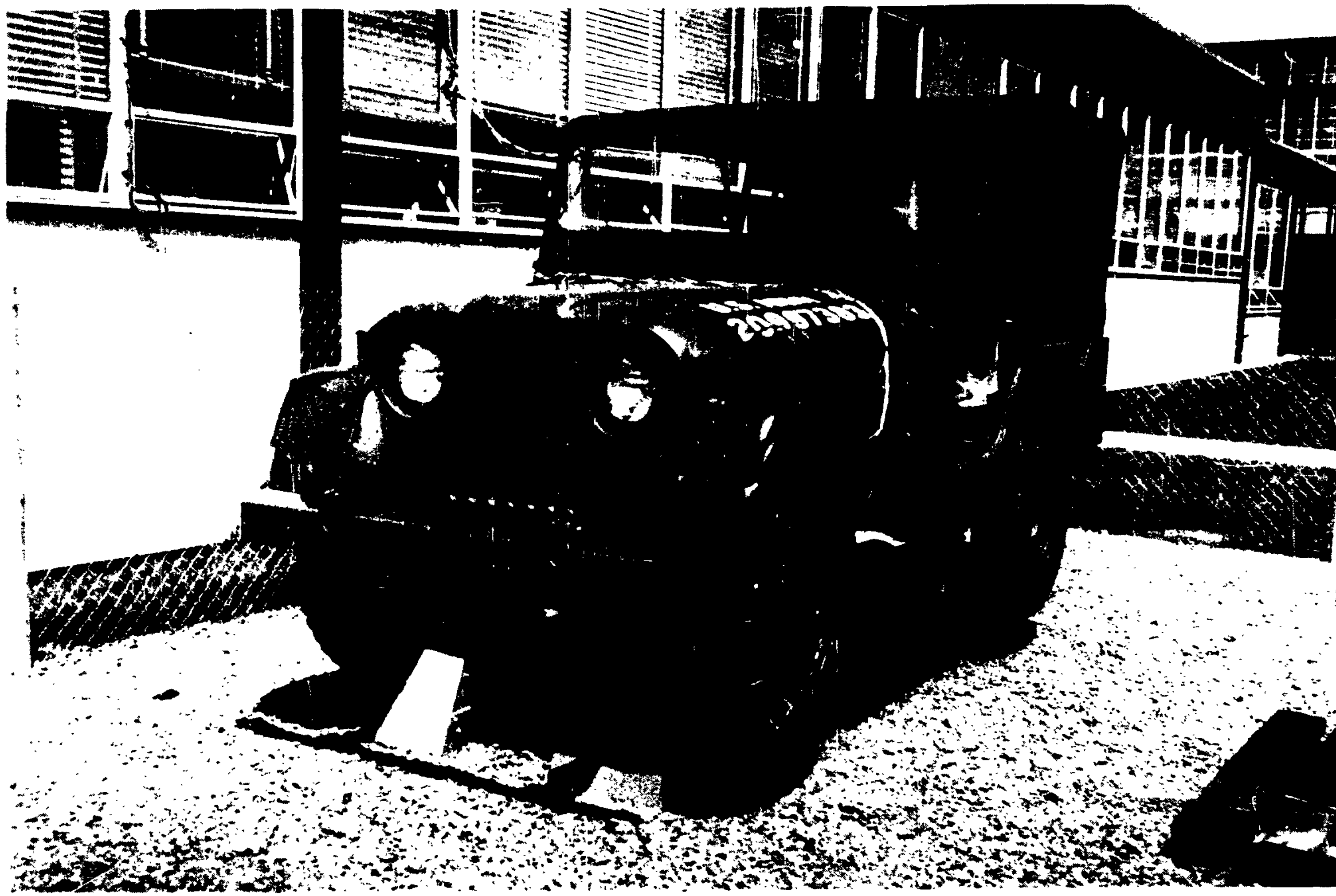
The degree of chalking or fading of the olive drab finish coat was determined by measuring the reflectance of the paint before and after 35 month exposure period.

COLOR	PERCENT REFLECTANCE	
	Before Exposure	After Exposure
Red	8.67	6.99
Green	7.95	6.68
Blue	6.17	5.28

Analysis of Photographic Data

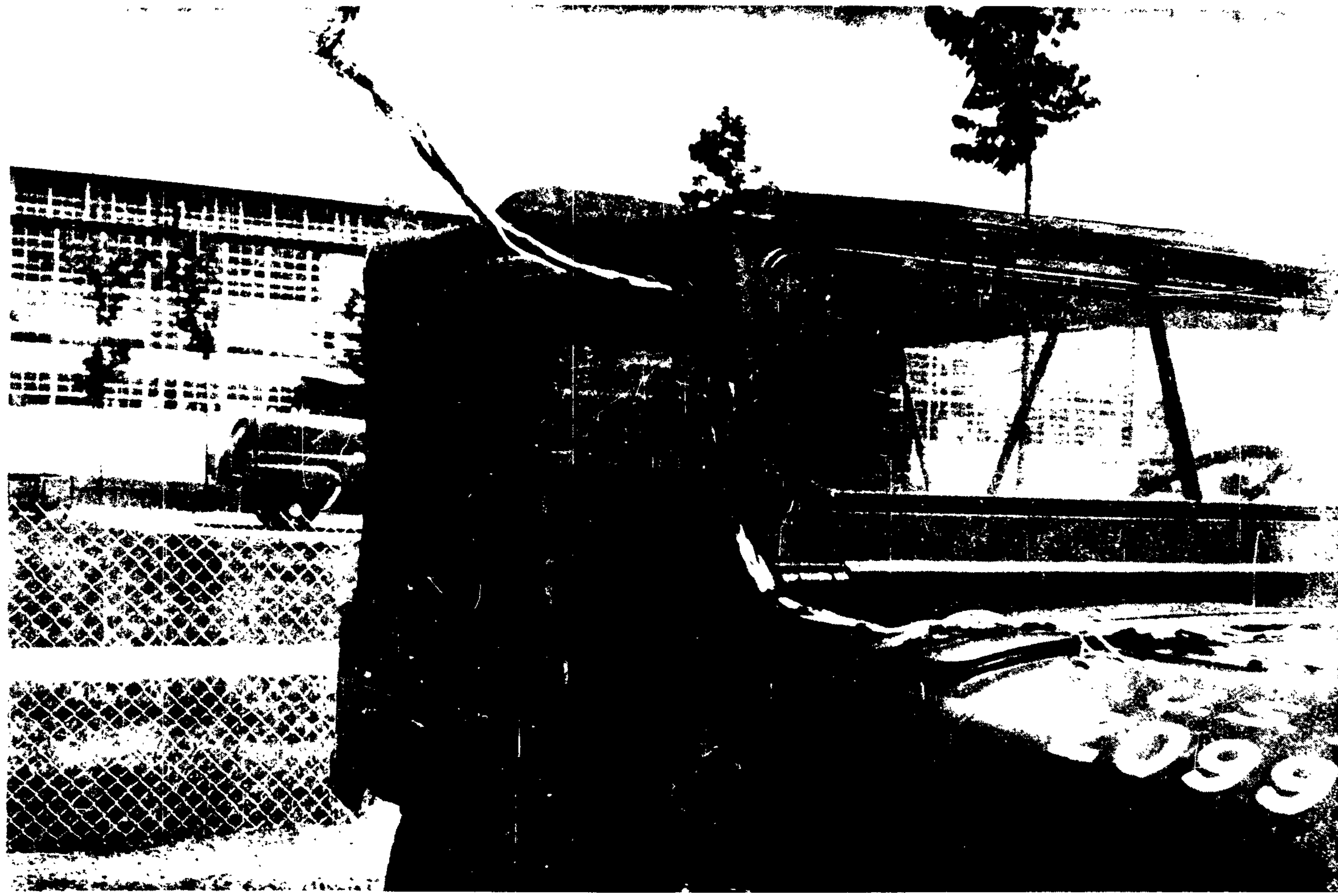
In general, the extent and progress of body corrosion and paint deterioration can be seen in the series of photographs, Figures 22 thru 80. A correlation between the performance of paint systems P, N, and O and corrosion failures or paint deterioration is outlined in Table VI.

The chalking and paint discoloration was the same for Systems P, N, and O. The chalking was quite noticeable, but did not relate to any apparent paint failure other than discoloration.



M-38 TEST VEHICLE SITUATED ON TEST STAND

FIGURE 22.

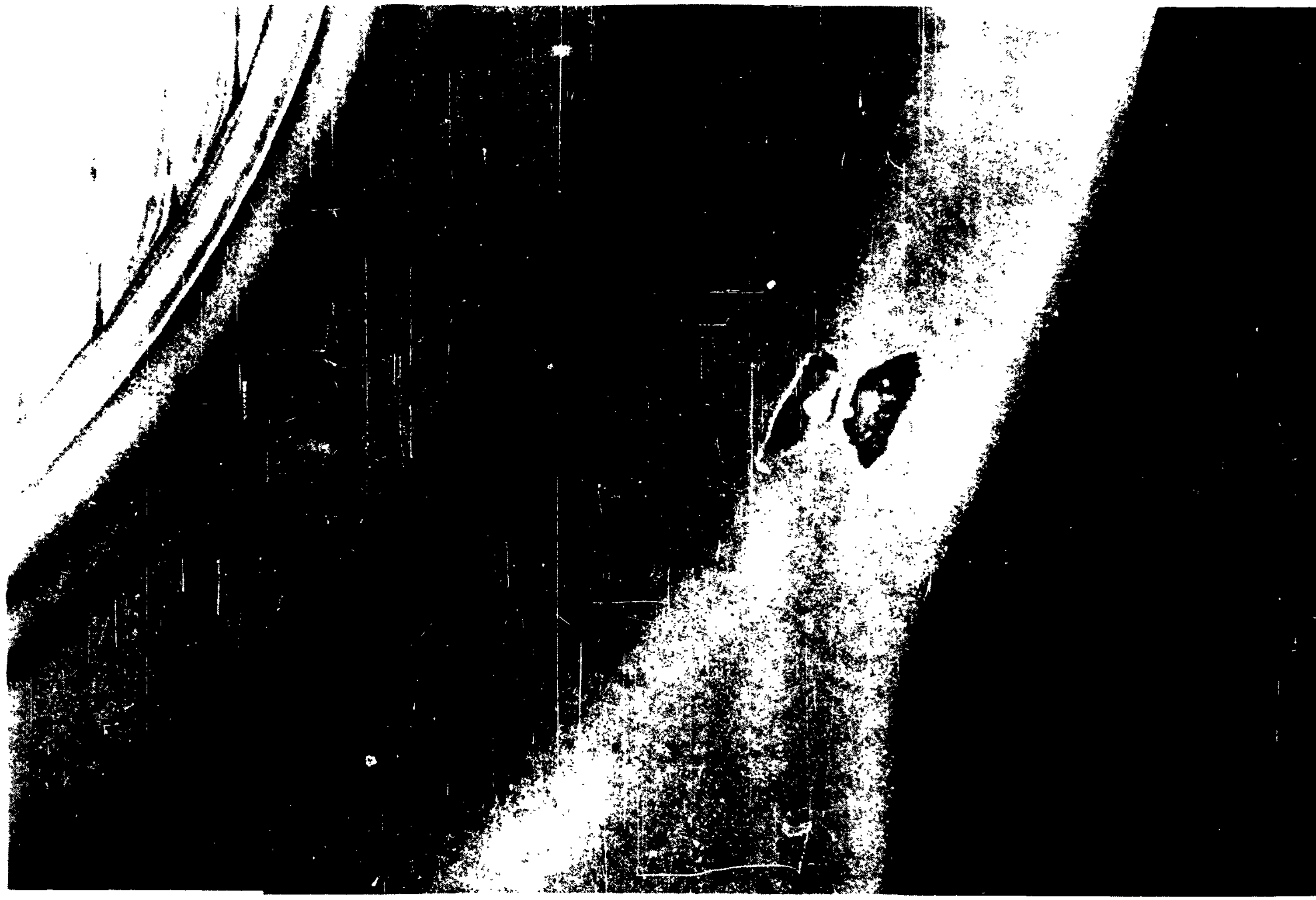


POWER CABLE ASSEMBLY TERMINATING TO VEHICLE

FIGURE 23.

INTERIOR VIEW OF M-38 TEST VEHICLE

FIGURE 24.

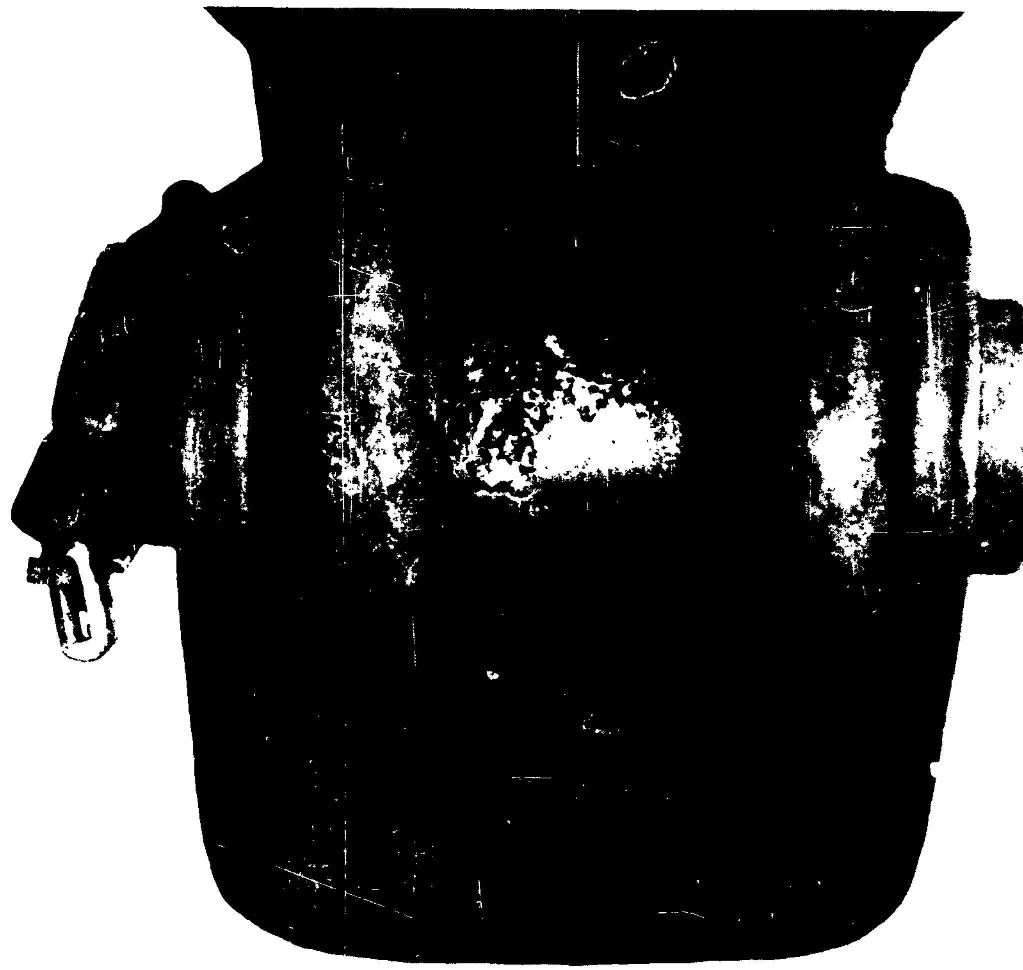


CORROSION OF BASE METAL PAINT CHIP ON FRONT GRILL AFTER
90 DAYS EXPOSURE

FIGURE 25

TYPICAL CORROSION AROUND BOLT HEAD AREAS ON LIGHT MOUNT, AFTER 90 DAYS EXPOSURE

FIGURE 26

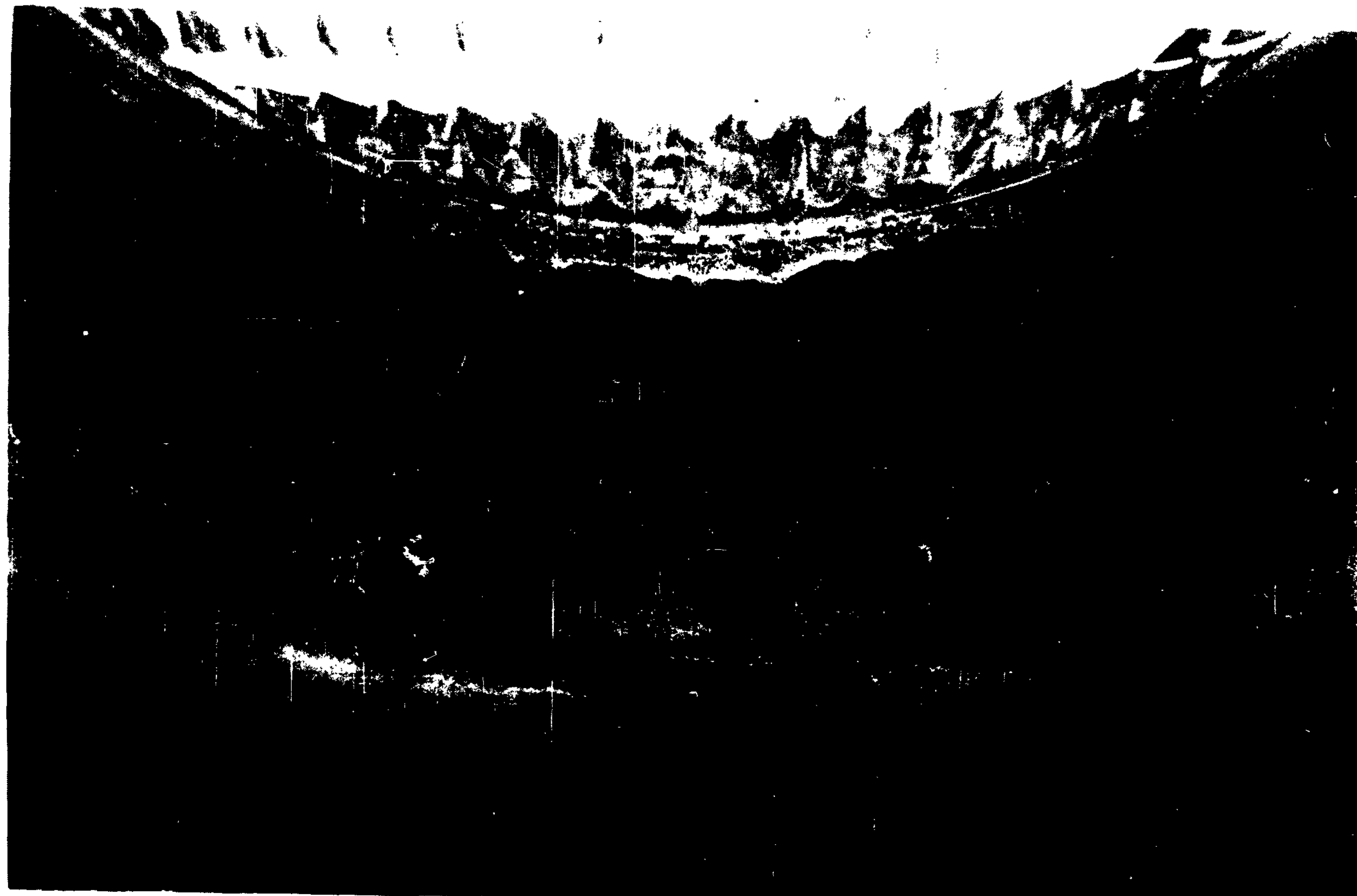


CORROSION AROUND FRONT PINTLE, AFTER 90 DAYS EXPOSURE

FIGURE 27.

CORROSION OF HOOD EDGE CAUSED BY HOOD LATCH STRIKING HOOD EDGE, AFTER 90 DAYS EXPOSURE

FIGURE 28



CORROSION STAIN BELOW FRONT HEAD LAMP CAUSED BY ACCUMULATION OF RUN-OFF WATER, AFTER 90 DAYS EXPOSURE

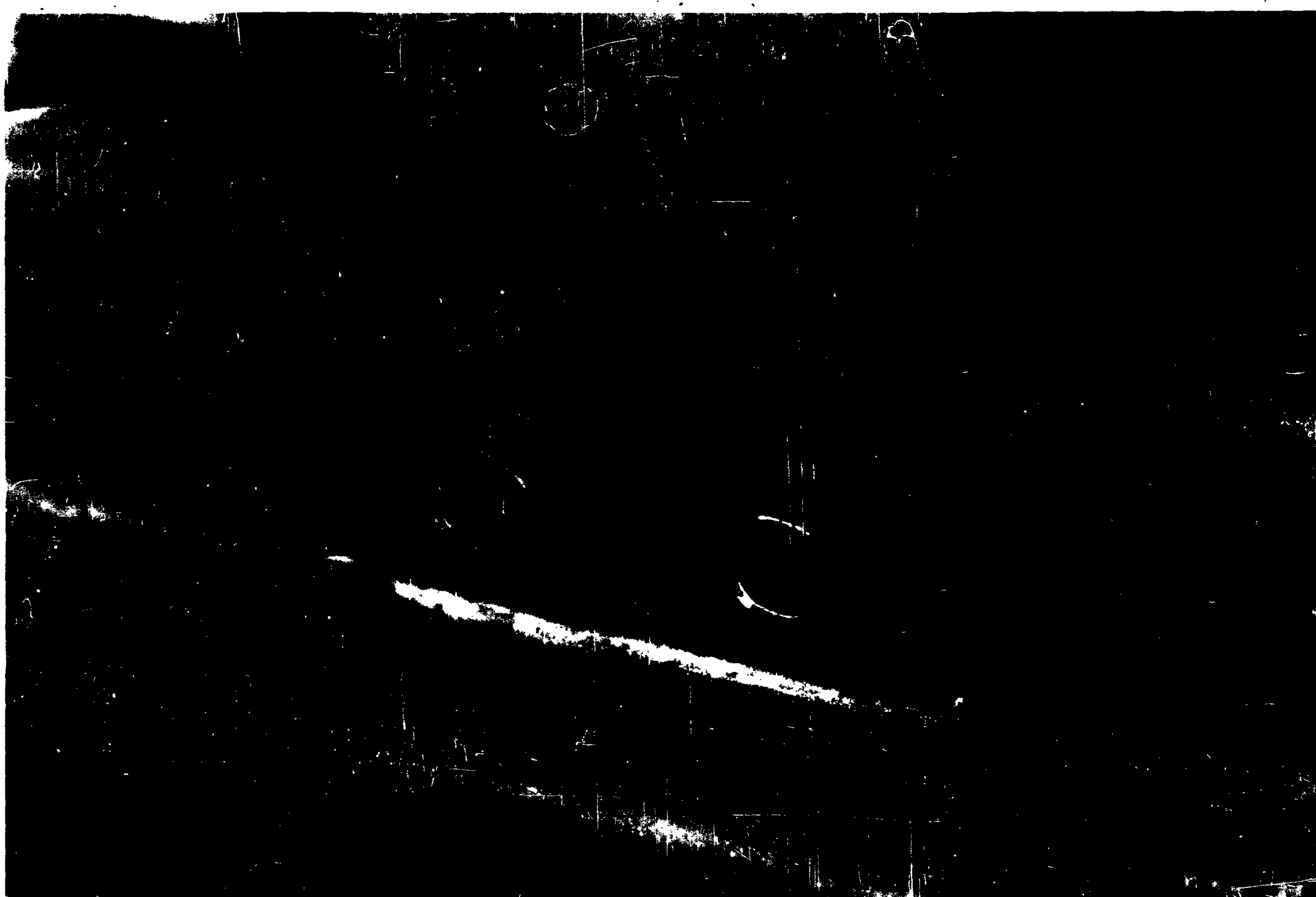
FIGURE 29

—DETROIT ARSENAL—

NEG. NO. C-60856 DATE 18 Sept 59

Red Corrosion Products on right front pintle hook (6 months exposure)

Figure 30

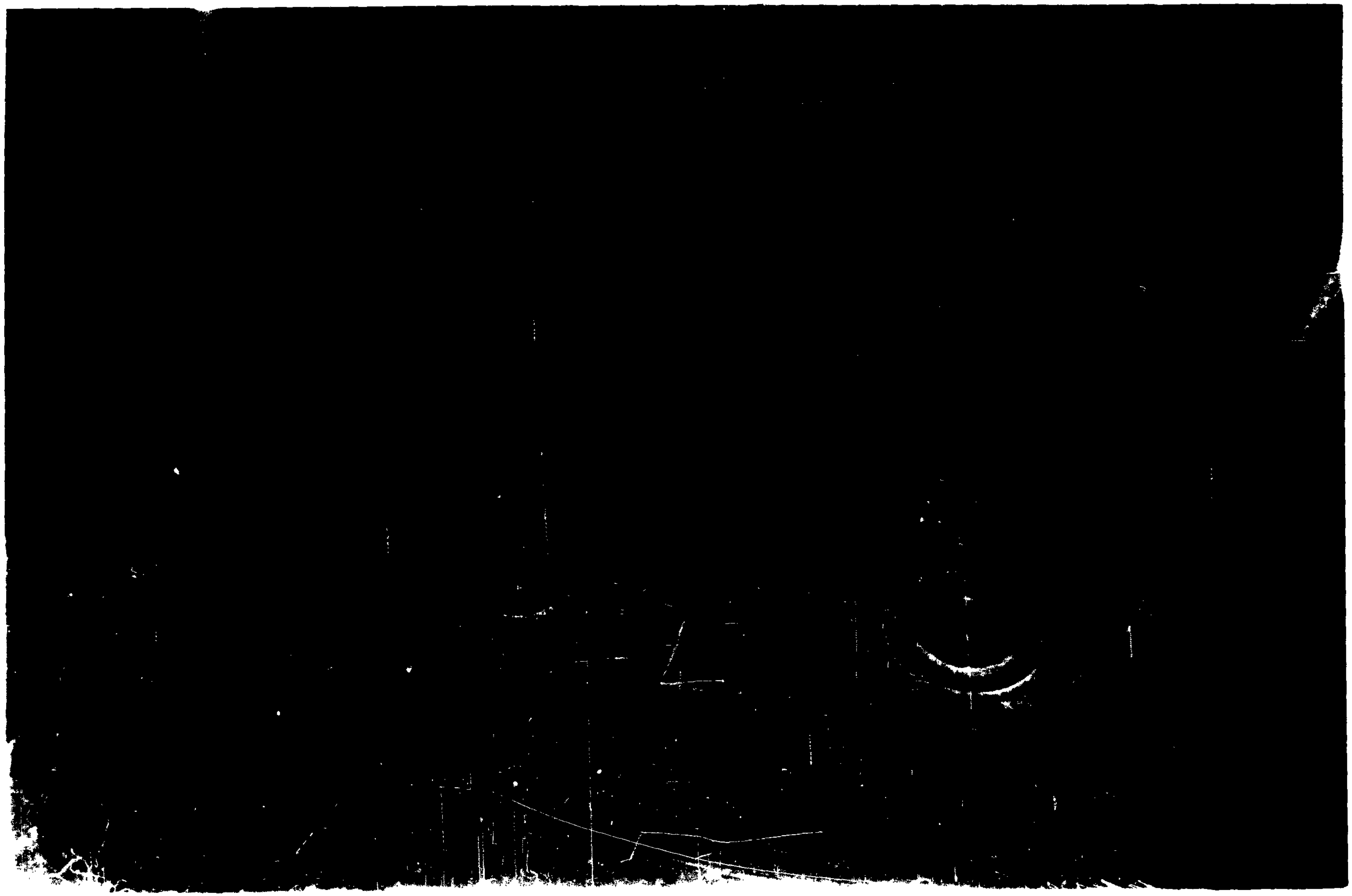


—DETROIT ARSENAL—

NEG. NO. C-60859 DATE 18 Sept 59

Red Corrosion Products on bolt caused by wrench (6 months exposure).

Figure 31



—DETROIT ARSENAL—

NEG. NO. C-60853 DATE 18 Sept 59

Red Corrosion Products around Bolt areas (6 months exposure)

Figure 32

—DETROIT ARSENAL—
NEG. NO. C-60857 DATE 18 Sept 59
White Corrosion Products visible as stains on grill (6 months exposure).

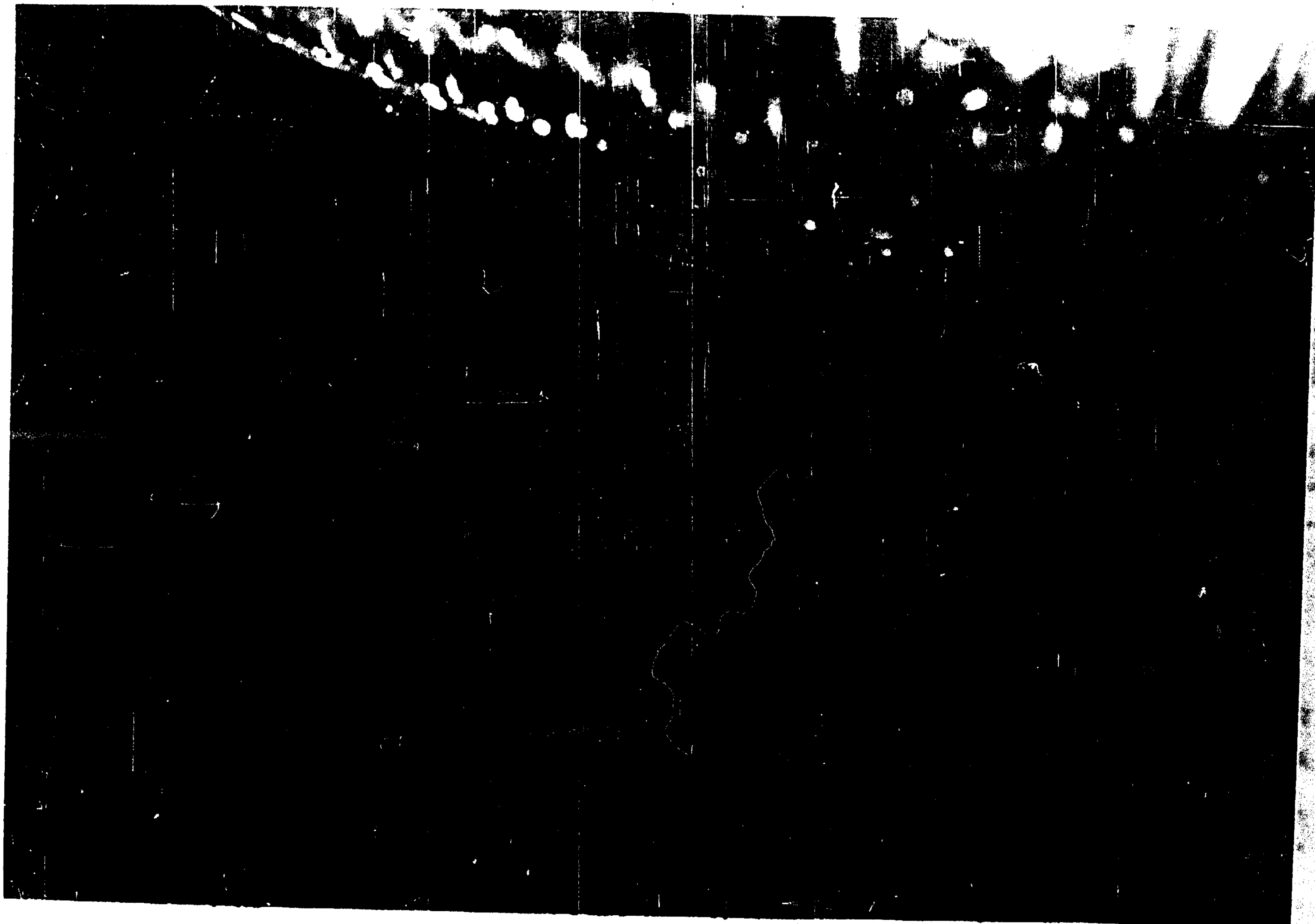
Figure 33

—DETROIT ARSENAL—

NEG. NO. C-60858 DATE 18 Sept 59

Chip thru paint on grill (6 months exposure).

Figure 34

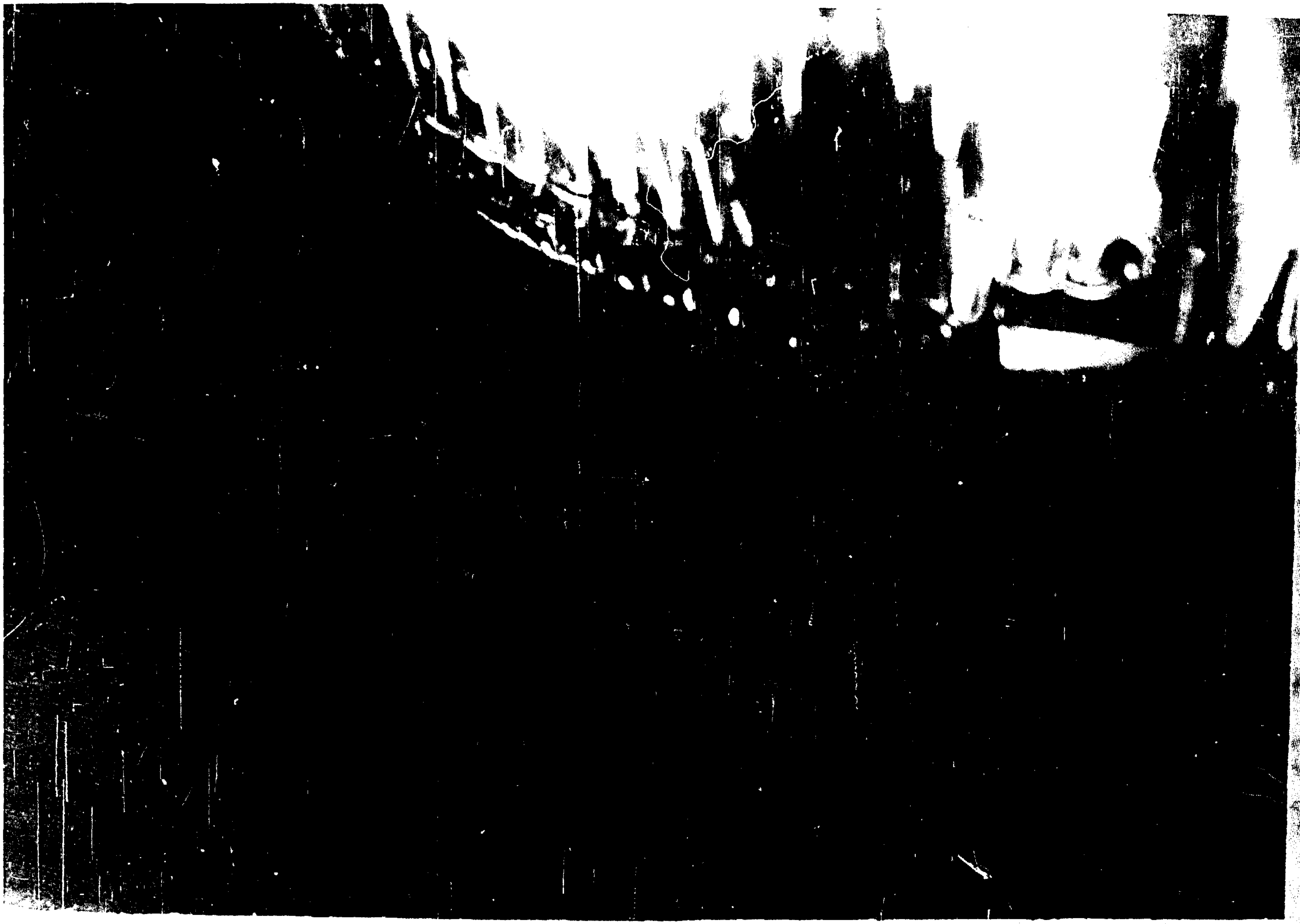


DETROIT ARSENAL

NEG. NO. C-60855 DATE 18 Sept 59

Corrosion Products in area of left head lamp (6 months exposure).

Figure 35



—DETROIT ARSENAL—

NEG. NO. C-60854 DATE 18 Sept 59

Corrosion Products in area of right head lamp (6 months exposure).

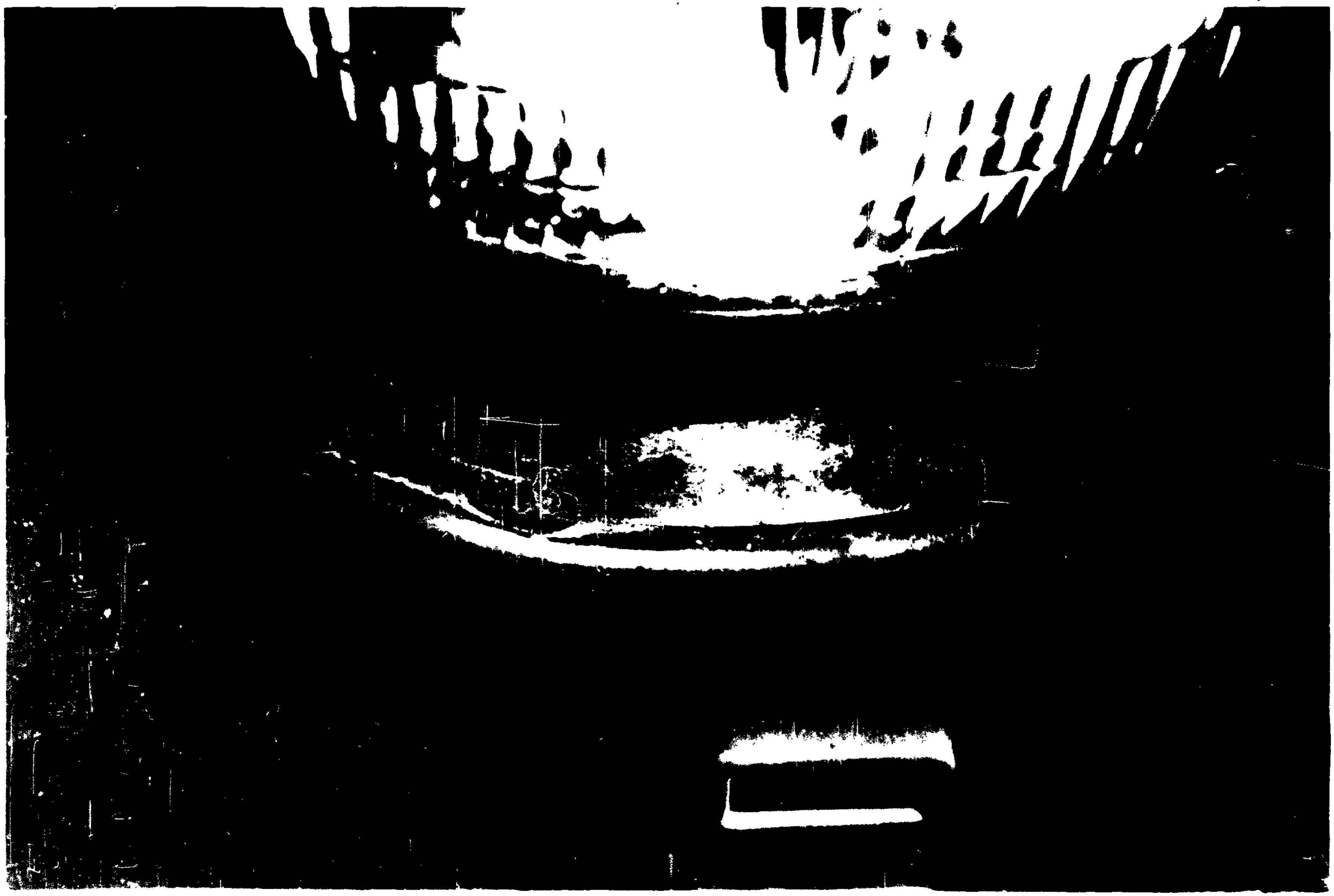
Figure 36

—DETROIT ARSENAL—

NEG. NO. C-63565 DATE 21 Jun 60

Battery cover after one year exposure. Note Corrosion along seam and blister.

Figure 37



—DETROIT ARSENAL—

NEG. NO. C-63559 DATE 21 Jun 60

Loss of Adhesion in Paint System - Left section of grill aro ·d light. Also note corrosion run-off products (chalking in light well. One year exposure.

Figure 38

DETROIT ARSENAL NEG. NO. C-63561 DATE 21 Jun 62
Lifting Electrode-right half hood. After one year exposure.

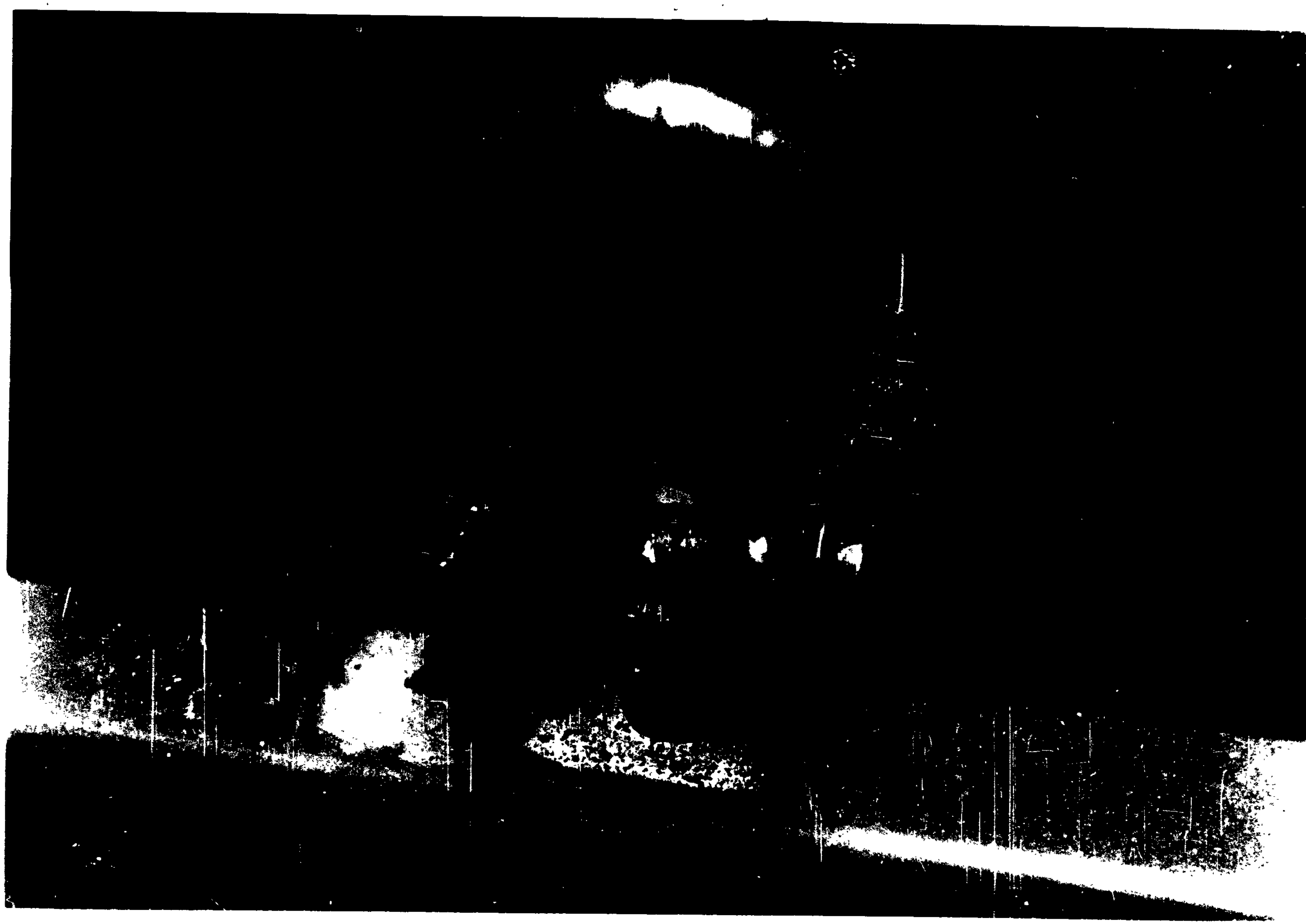
Figure 39

—DETROIT ARSENAL—

NEG. NO. C-63562 DATE 21 Jun 60

Corrosion in area of seam. Top left rear wheel well. After one year exposure.

Figure 40



—DETROIT ARSENAL—
NEG. NO. C-63564 DATE 21 Jun 60
Left Pintle hook after one year exposure.

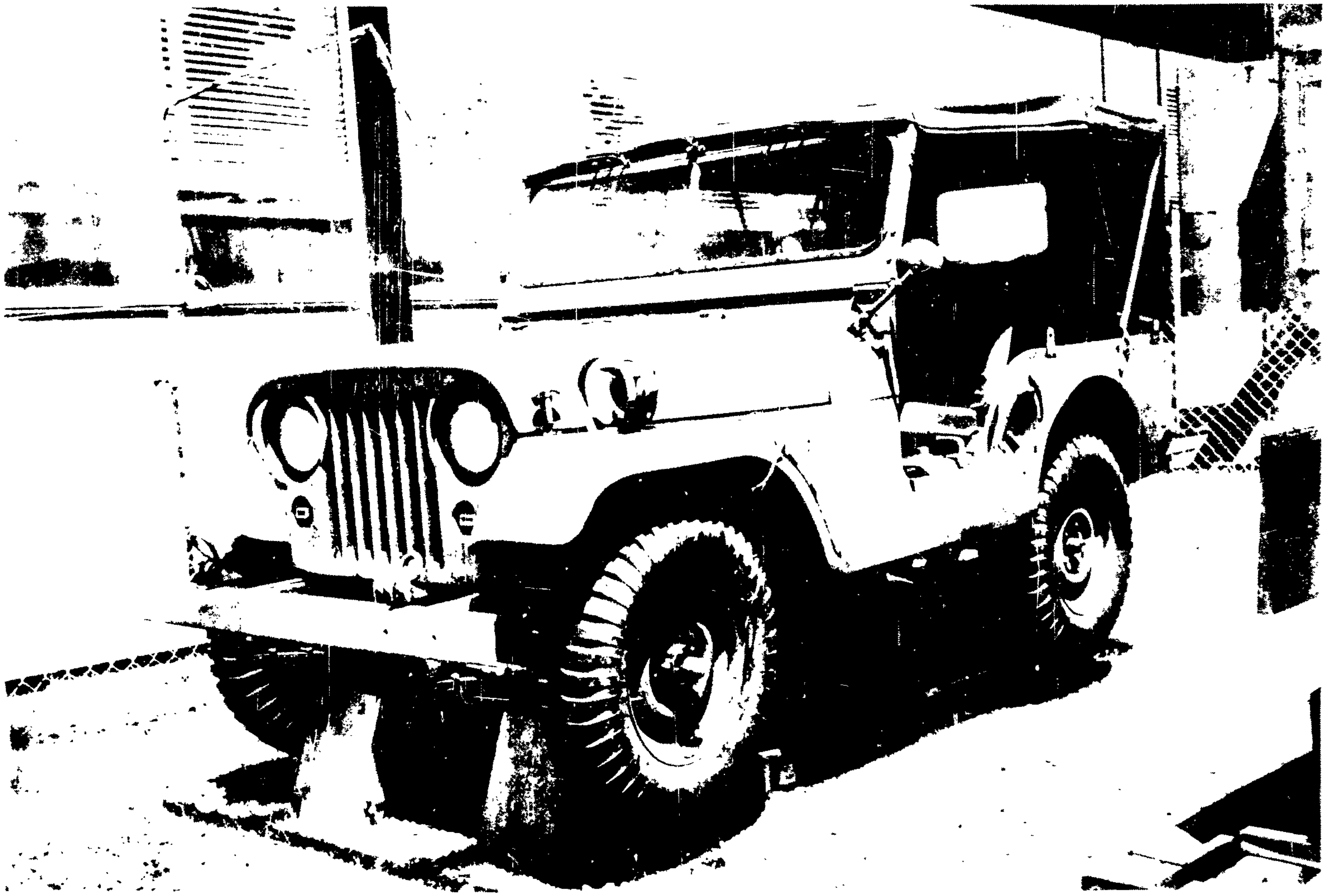
Figure 41

—DETROIT ARSENAL—

NEG. NO. C-63560 DATE 21 Jun 60

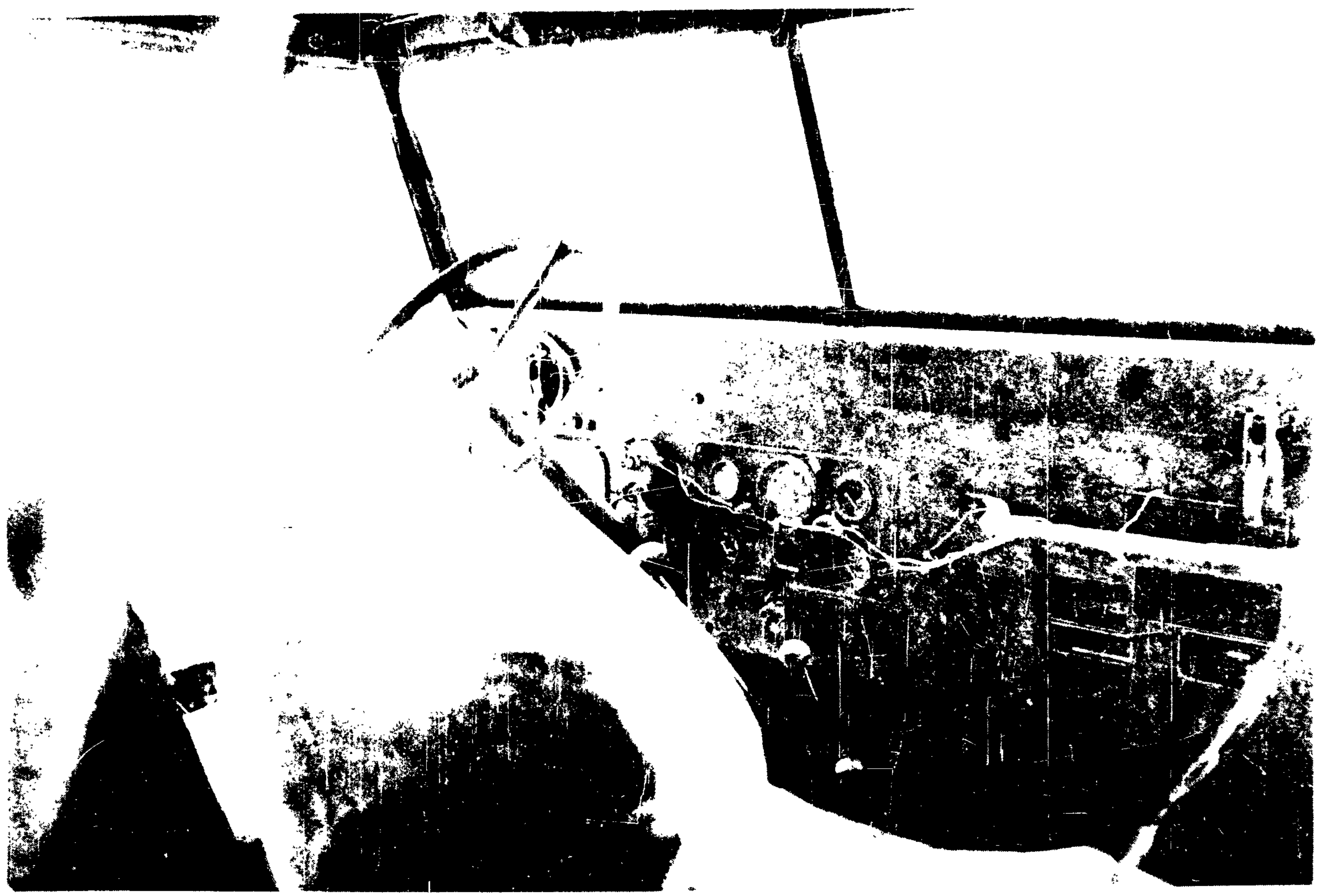
Corrosion around bolt heads. After one year exposure.

Figure 42



M-38-A1 TEST VEHICLE AFTER 25 MONTHS EXPOSURE

FIGURE 43

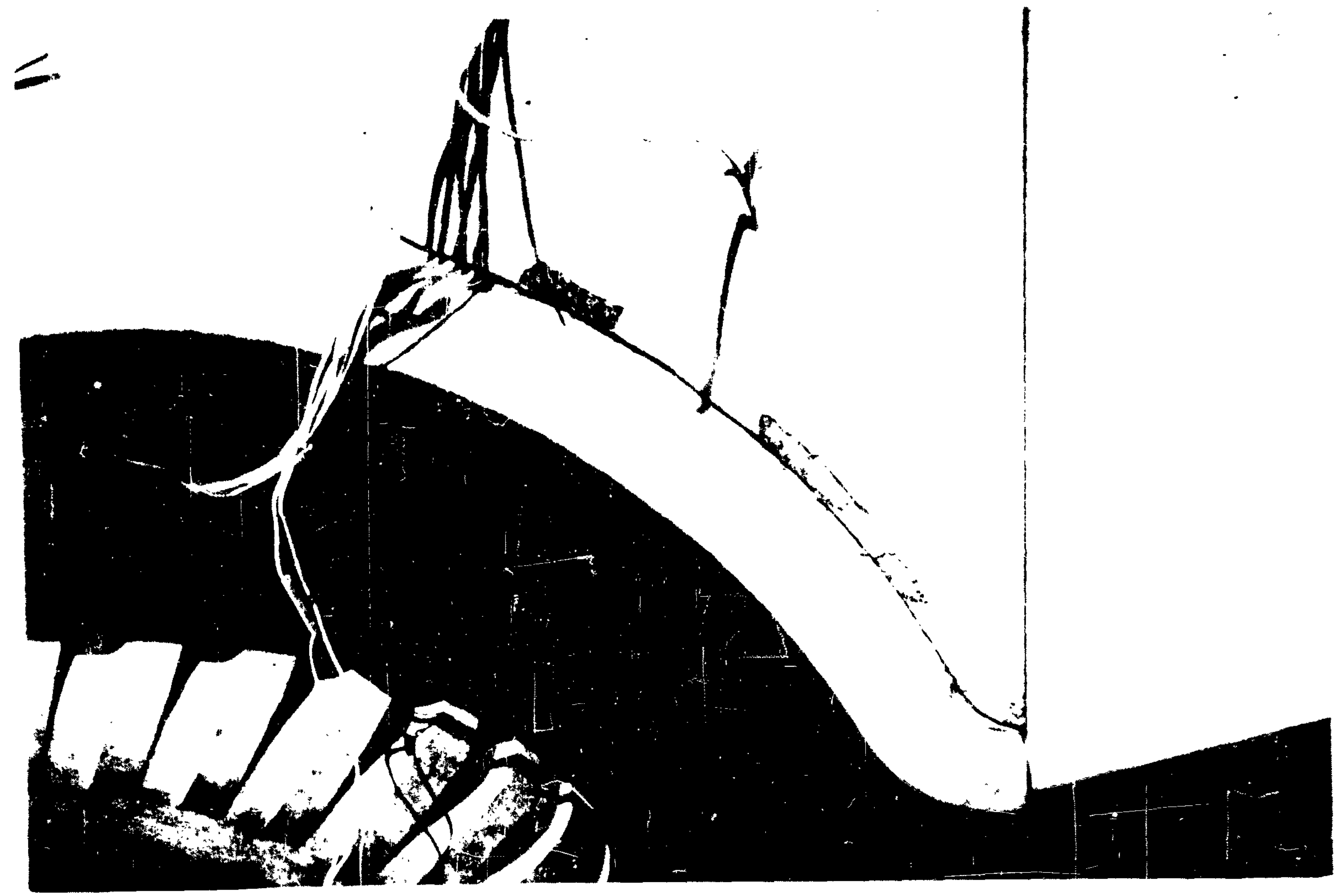


M-38-A1 TEST VEHICLE AFTER 25 MONTHS EXPOSURE - INTERIOR VIEW

FIGURE 44

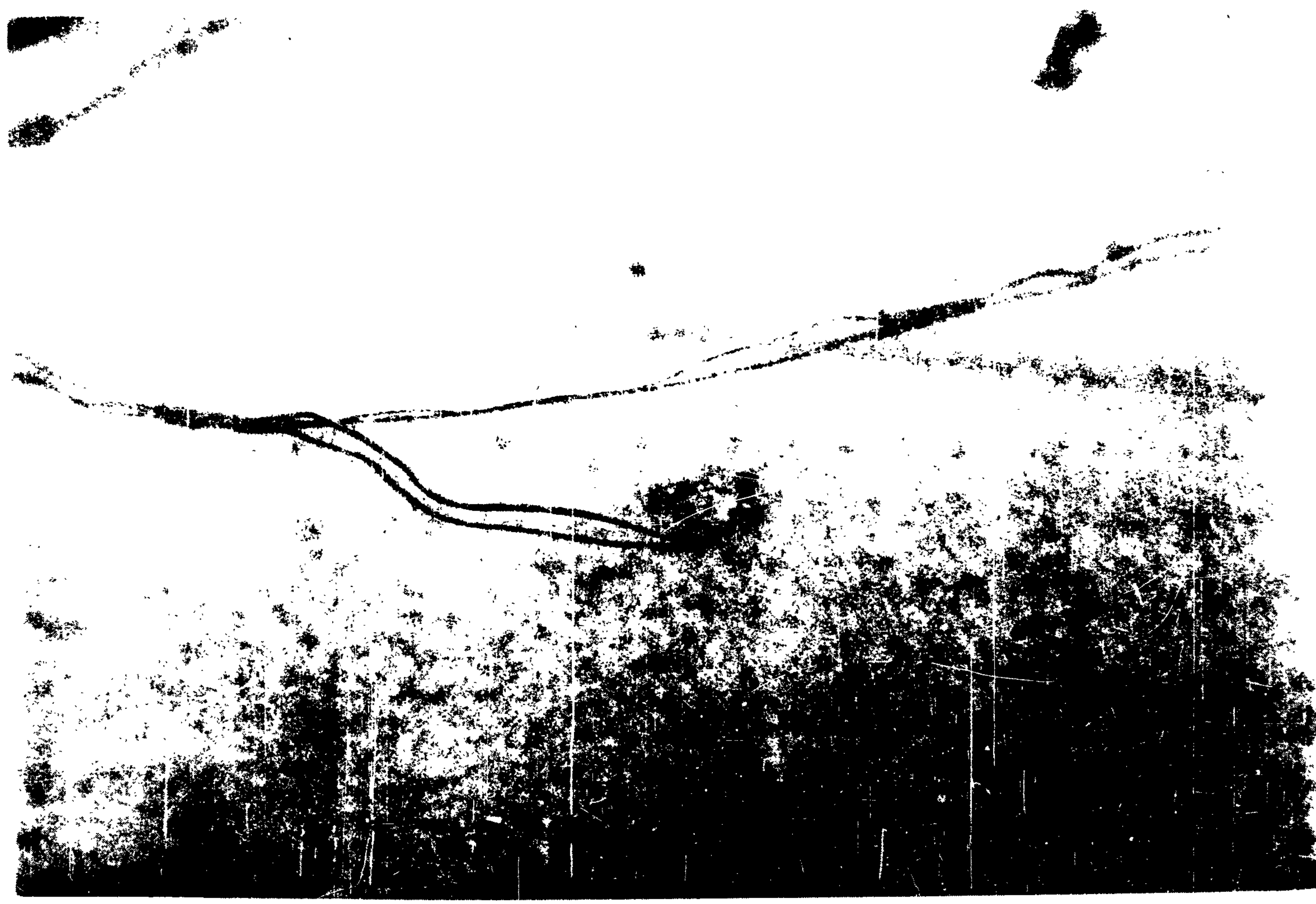
CORROSION UNDER RIGHT FRONT HEADLAMP AFTER 25 MONTHS EXPOSURE

FIGURE 45



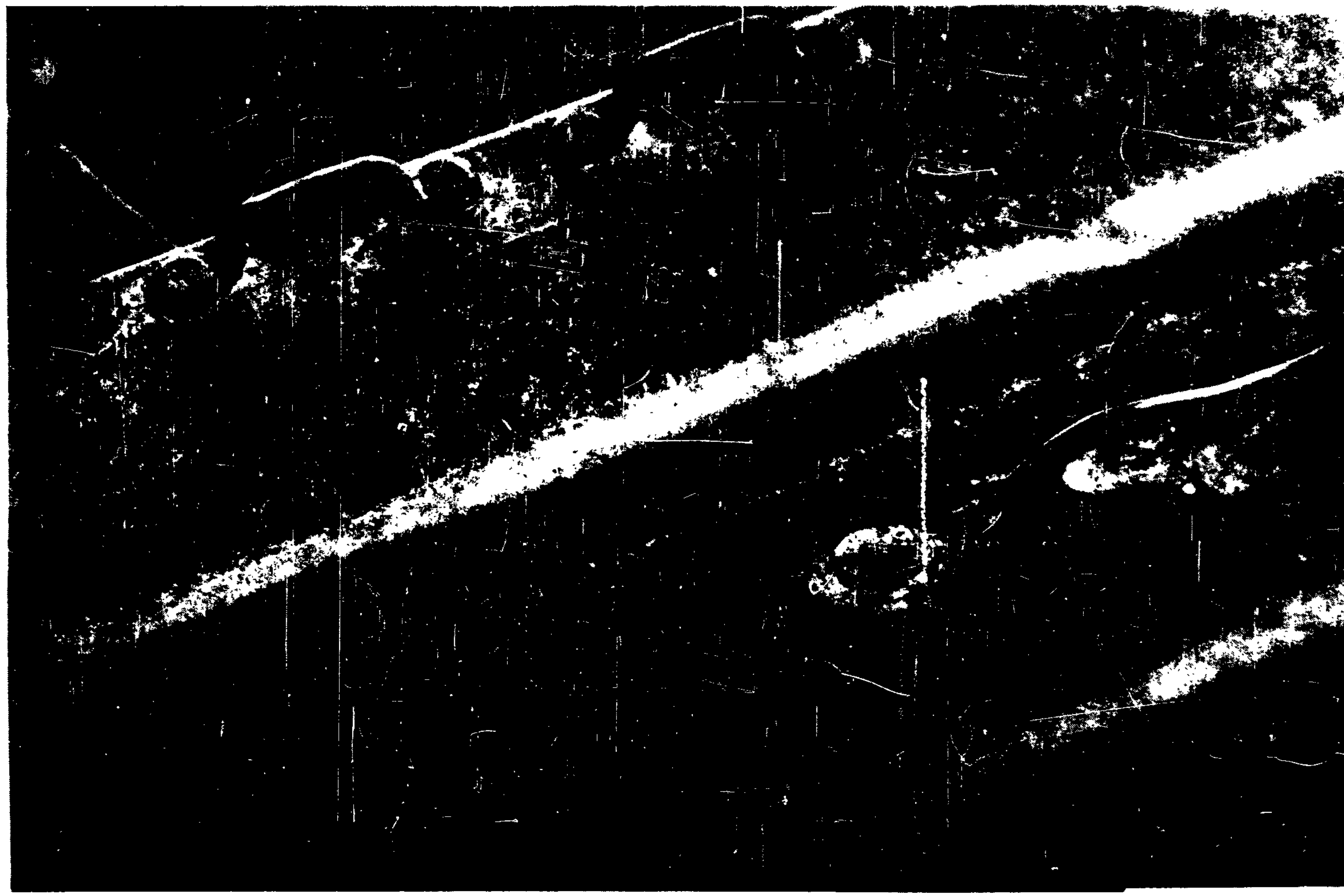
CORROSION ON MASKED EDGE OF LEFT FRONT QUARTER PANEL AFTER
25 MONTHS EXPOSURE

FIGURE 46



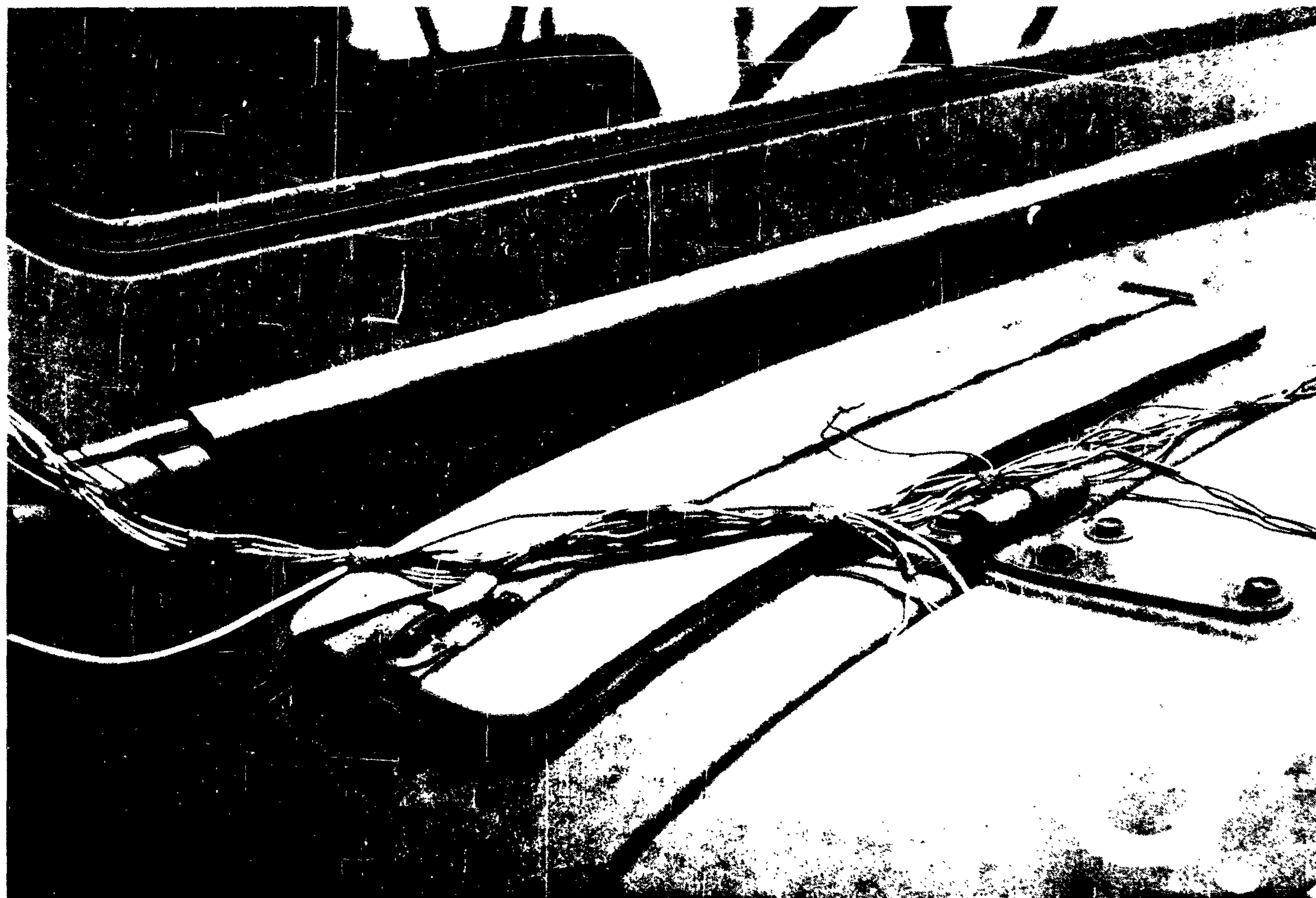
LOOSE ELECTRODE ON RIGHT SIDE OF HOOD AFTER 25 MONTHS EXPOSURE

FIGURE 47



LOOSE TERMINAL ON INSIDE OF RIGHT REAR WHEEL WELL AFTER 25 MONTHS EXPOSURE

FIGURE 48



CORROSION ON BATTERY COVER PANEL AFTER 25 MONTHS EXPOSURE

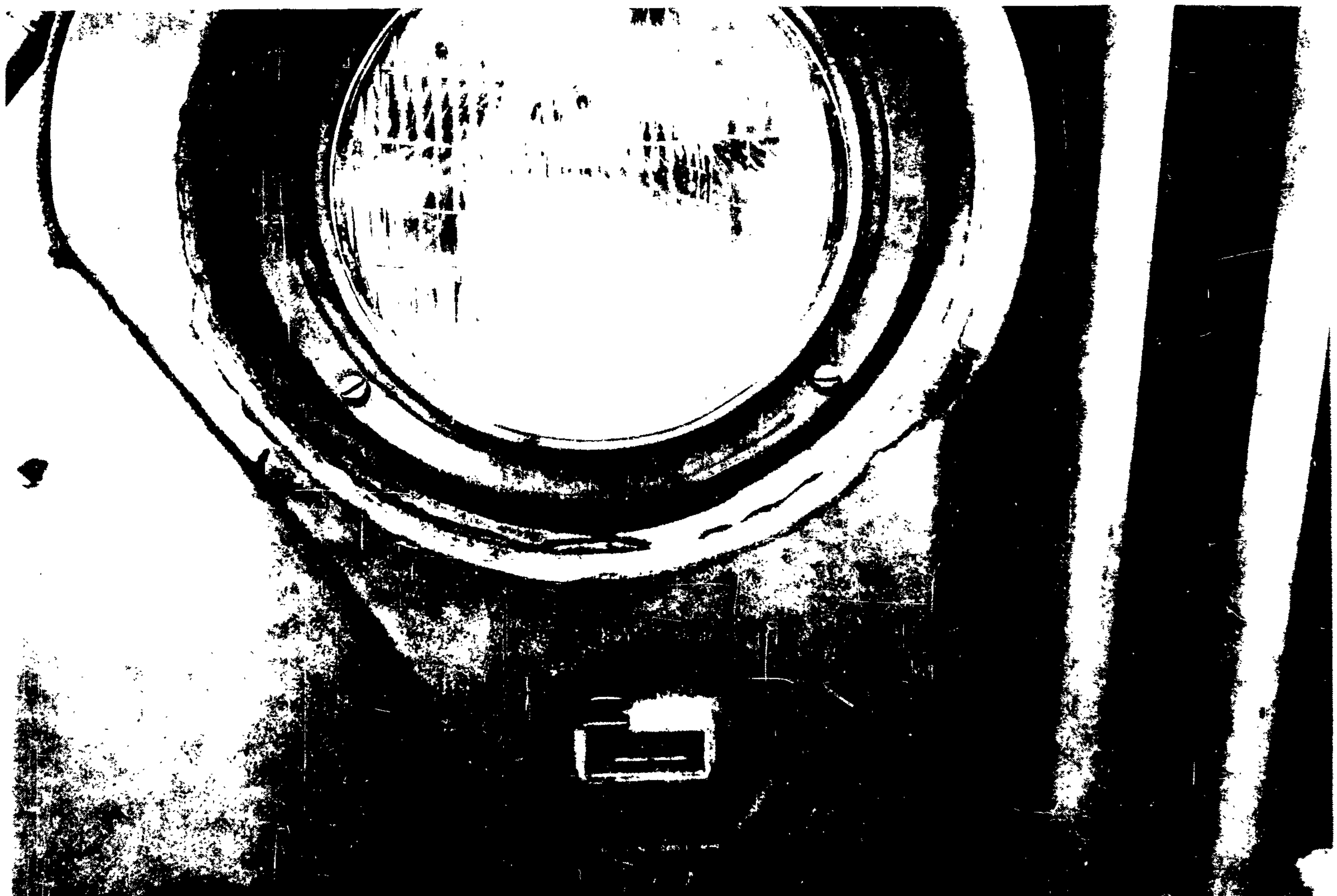
FIGURE 49

M38A1. CORROSION ON BATTERY COVER PANEL AFTER 34 MONTHS EXPOSURE

FIGURE 50

M38A1, CORROSION UNDER RIGHT HEADLAMP AFTER 34 MONTHS OUTSIDE EXPOSURE

FIGURE 51



M38A1, CORROSION UNDER LEFT HEADLAMP AFTER 34 MONTHS OUTSIDE EXPOSURE

FIGURE 52.

M38A1, LOSS OF ELECTRODE ON HOOD AFTER 34 MONTHS OUTSIDE EXPOSURE

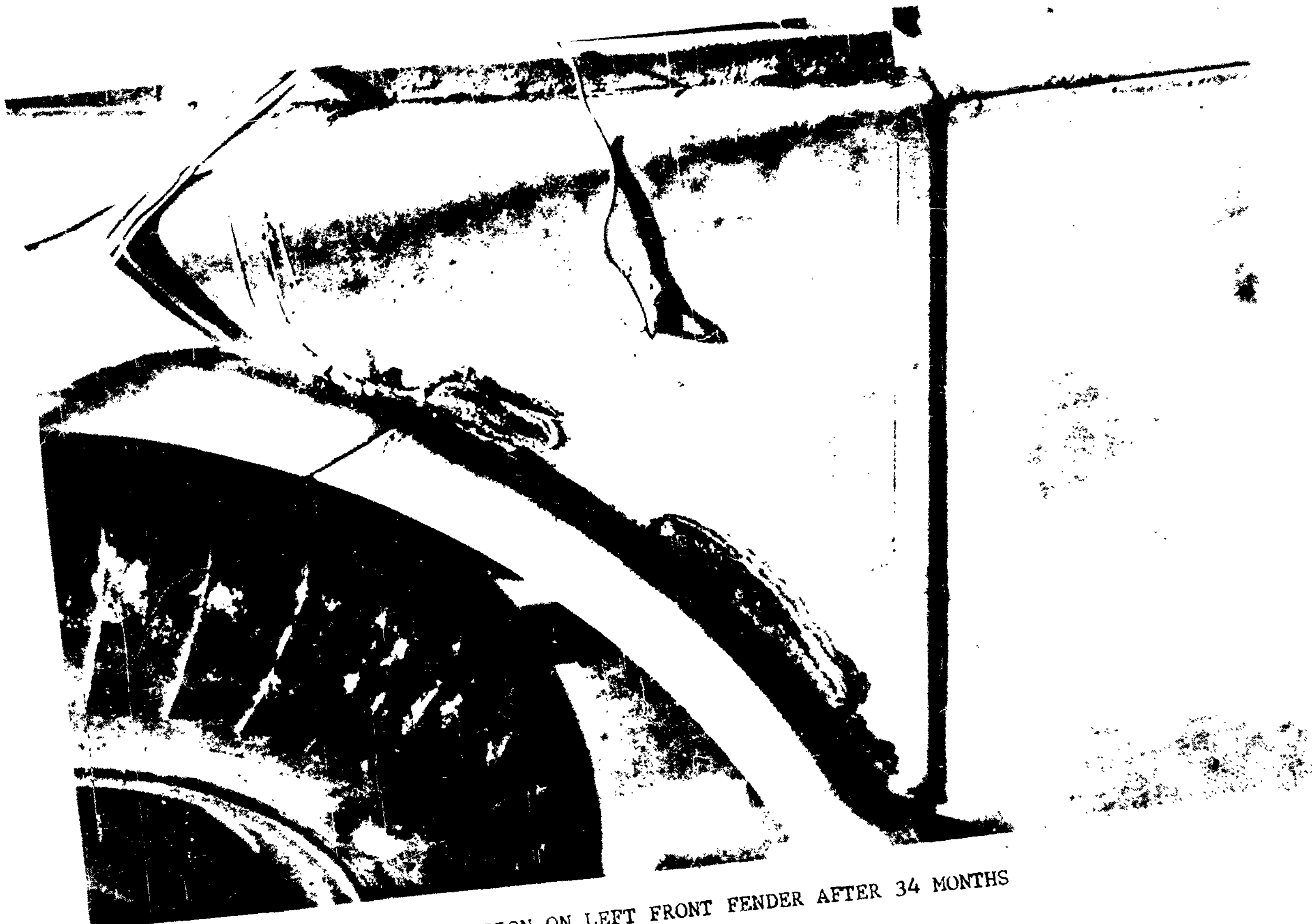
FIGURE 53

M38A1, CORROSION IN SEAM AREA. LEFT BODY PANEL

FIGURE 54

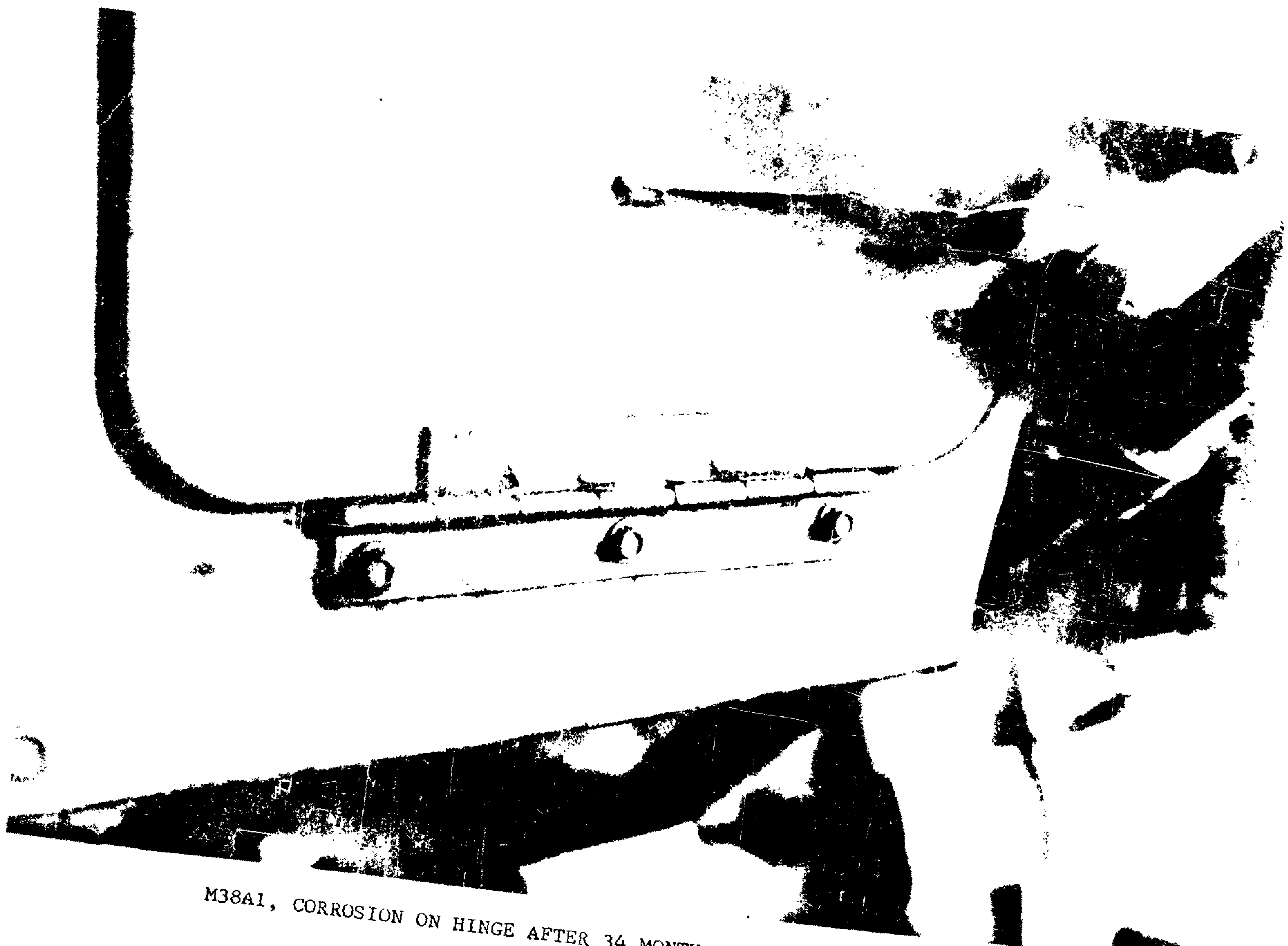
M38A1. CORROSION IN GRILLE AREA AFTER 34 MONTHS OUTSIDE EXFOSURE

FIGURE 55



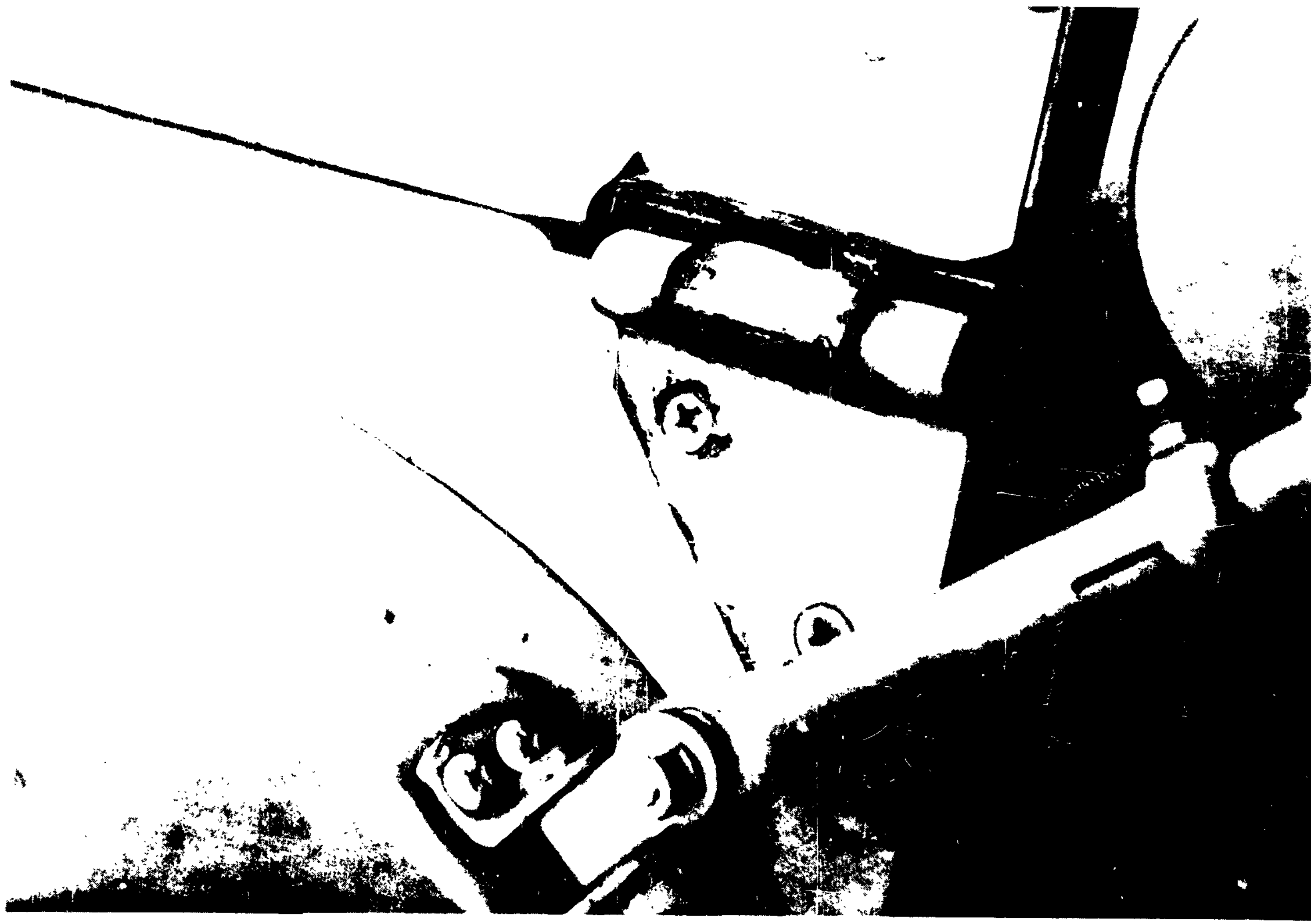
M38A1, CORROSION ON LEFT FRONT FENDER AFTER 34 MONTHS
OUTSIDE EXPOSURE

FIGURE 56.



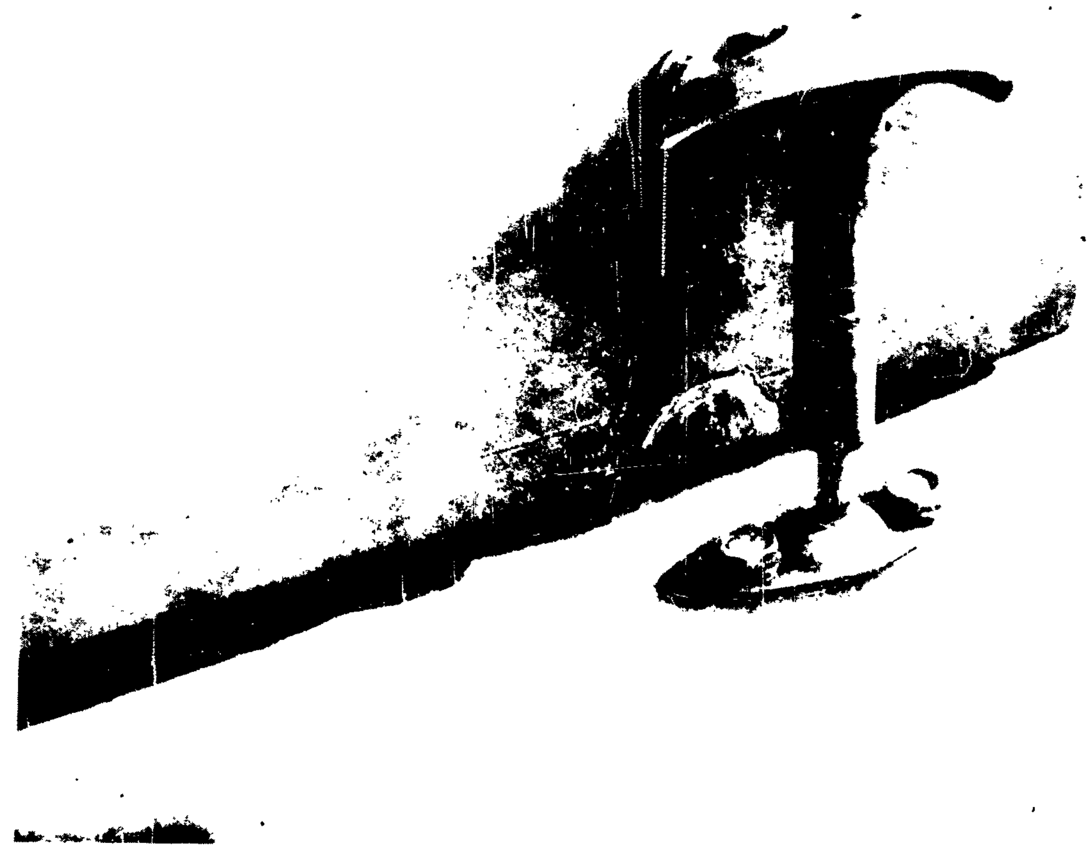
M38A1, CORROSION ON HINGE AFTER 34 MONTHS OUTSIDE EXPOSURE

FIGURE 57.



M38A1, CORROSION ON WINDSHIELD HINGE AFTER 34 MONTHS OUTSIDE EXPOSURE

FIGURE 58.

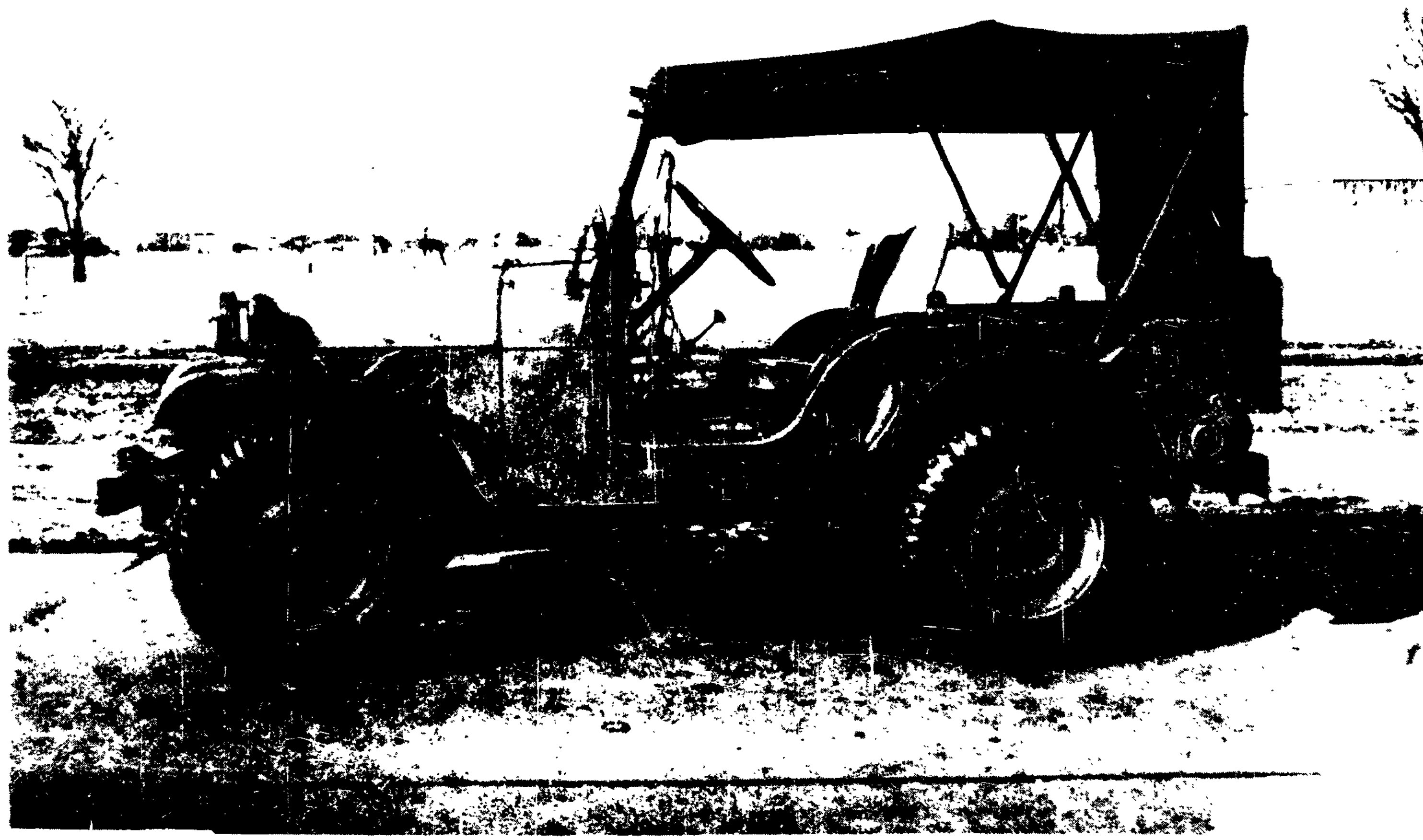


M38A1, TYPICAL CORROSION OF BOLT HEADS AFTER 34 MONTHS OUTSIDE EXPOSURE

FIGURE 59.

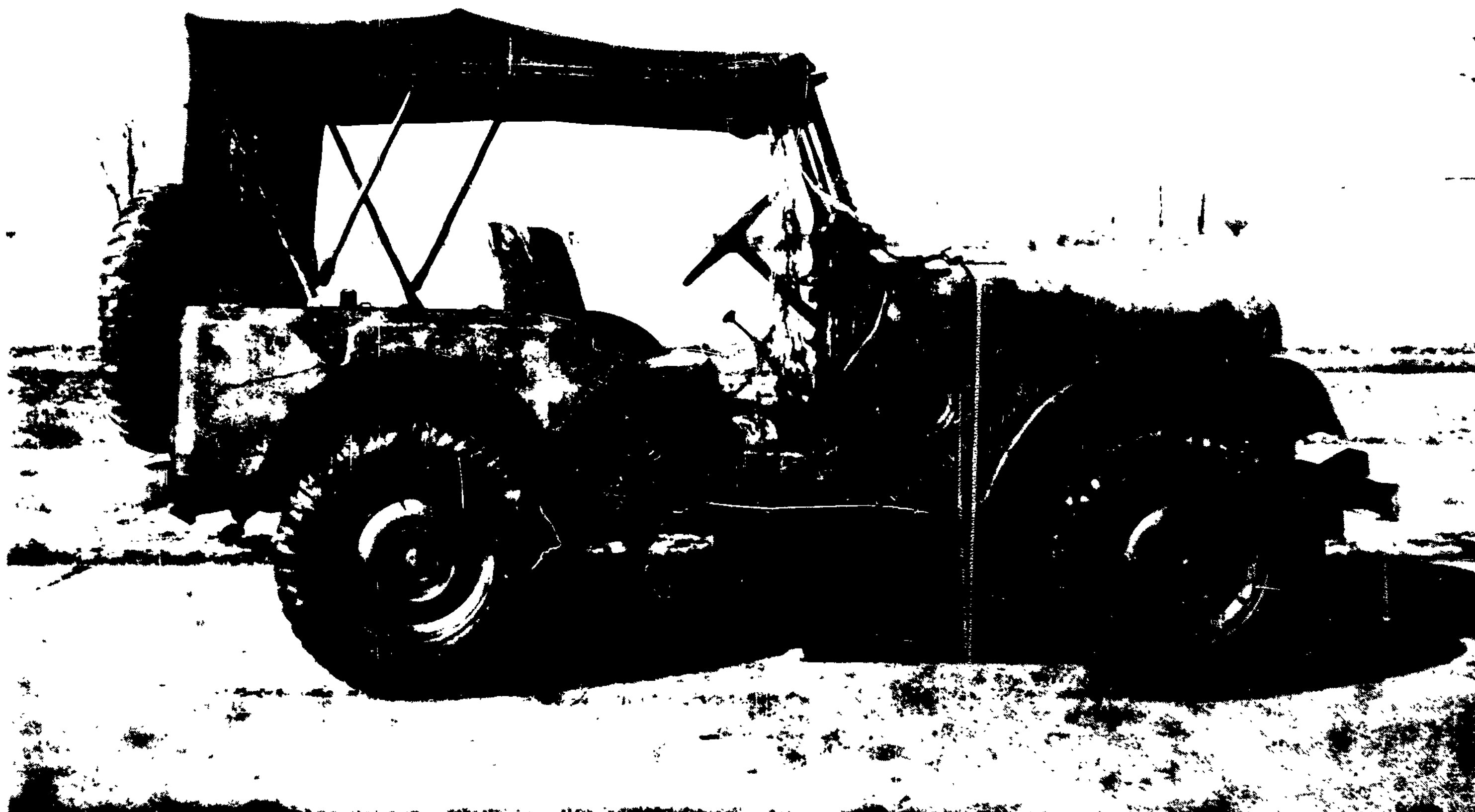
M38A1. CORROSION IN SEAM AREA OF REAR FLOOR MEMBER AFTER 35 MONTHS OUTSIDE EXPOSURE

FIGURE 60



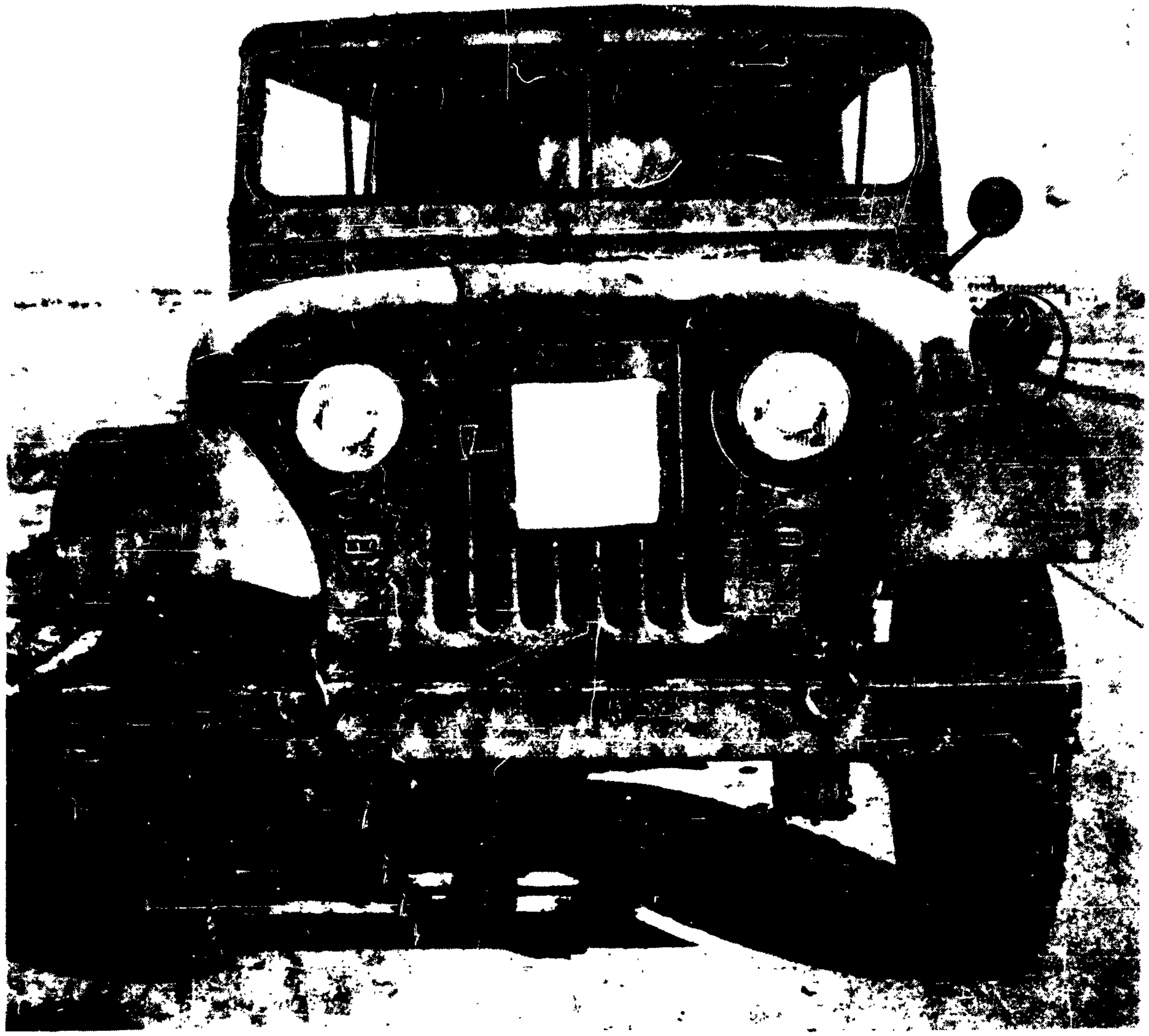
M38A1 TEST VEHICLE AFTER 35 MONTHS EXPOSURE (COMPLETION OF TEST)

FIGURE 61



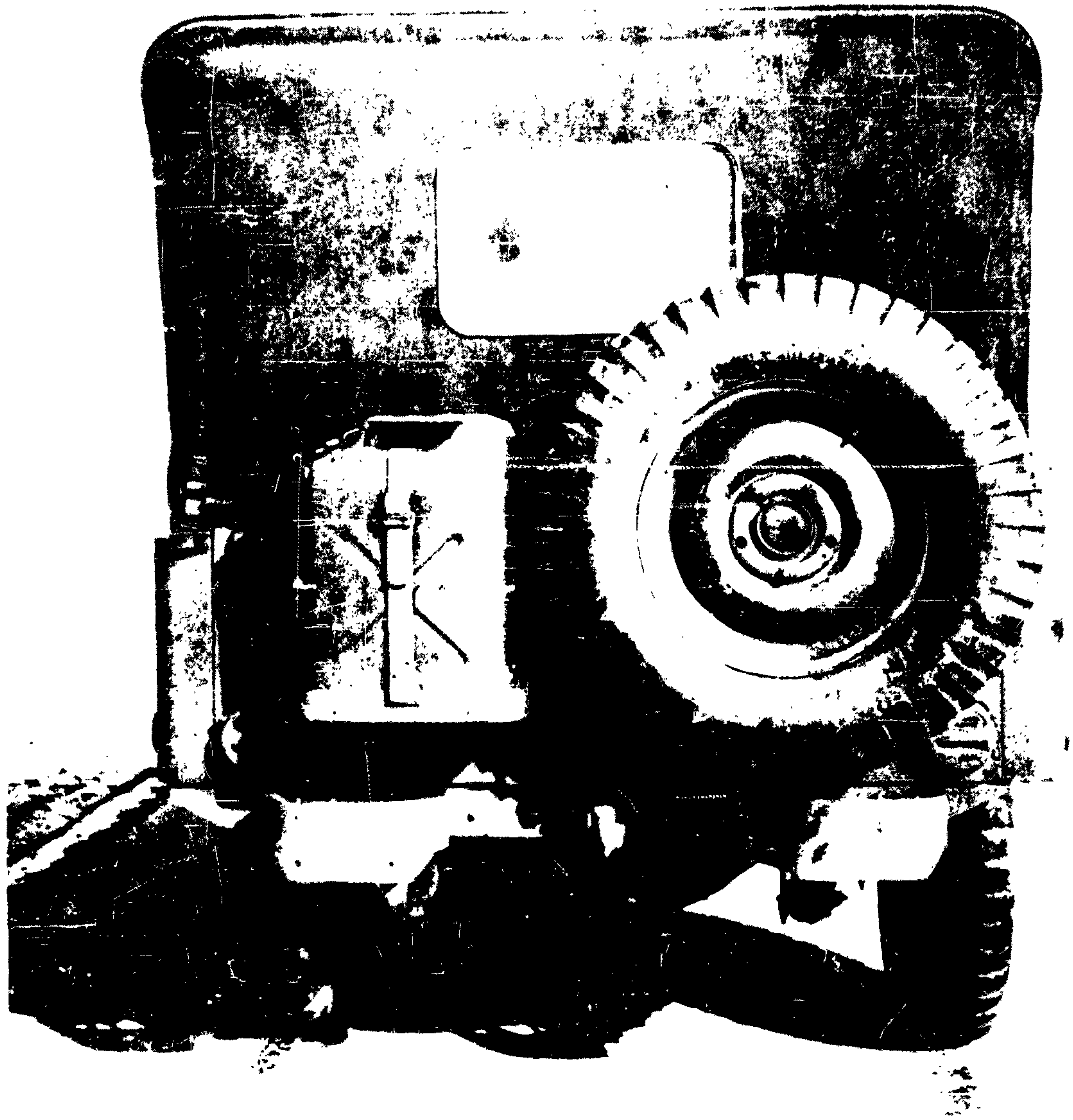
M38A1 TEST VEHICLE AFTER 35 MONTHS EXPOSURE (COMPLETION OF TEST).

FIGURE 62



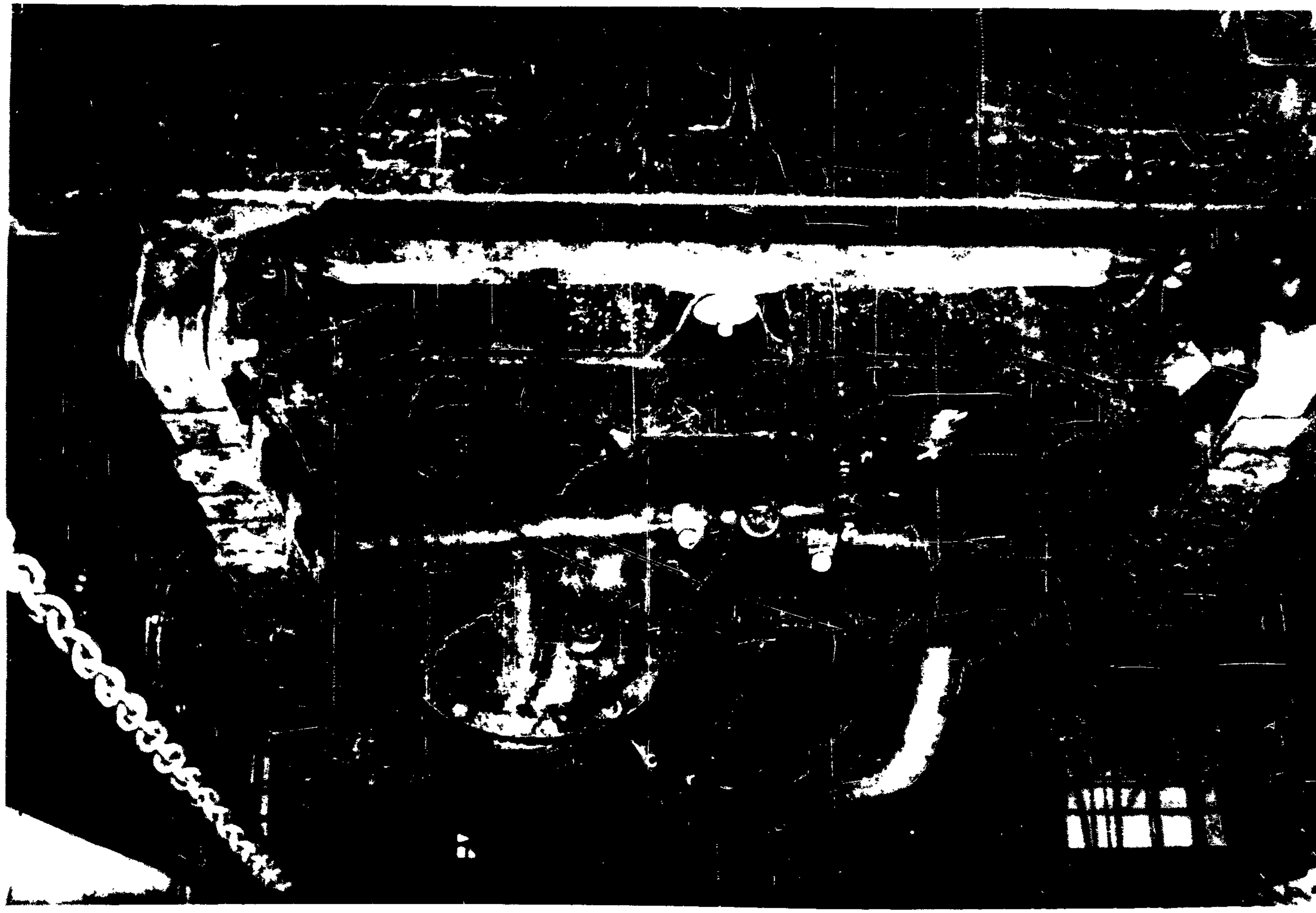
M38A1 TEST VEHICLE AFTER 35 MONTHS EXPOSURE (COMPLETION OF TEST)

FIGURE 63



M38A1 TEST VEHICLE AFTER 35 MONTHS EXPOSURE (COMPLETION OF TEST)

FIGURE 64

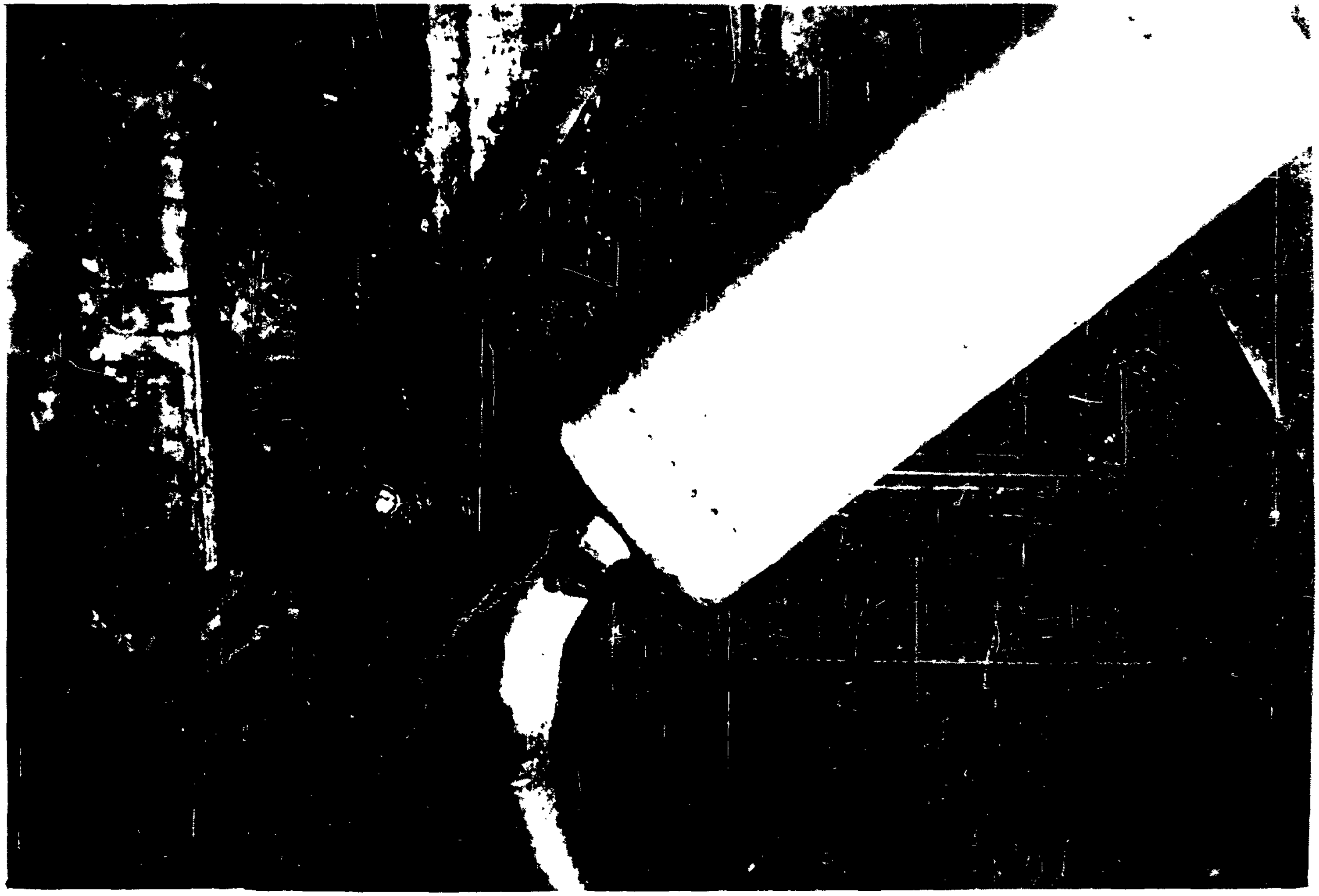


M-38-A1, CONDITION OF UNDERSIDE OF VEHICLE PRIOR TO ATMOSPHERIC EXPOSURE TESTS (M-38-A1 TEST VEHICLE)

FIGURE 65

M-38-A1, CONDITION OF UNDERSIDE OF VEHICLE PRIOR TO ATMOSPHERIC EXPOSURE TESTS (M-38-A1 TEST VEHICLE)

FIGURE 66

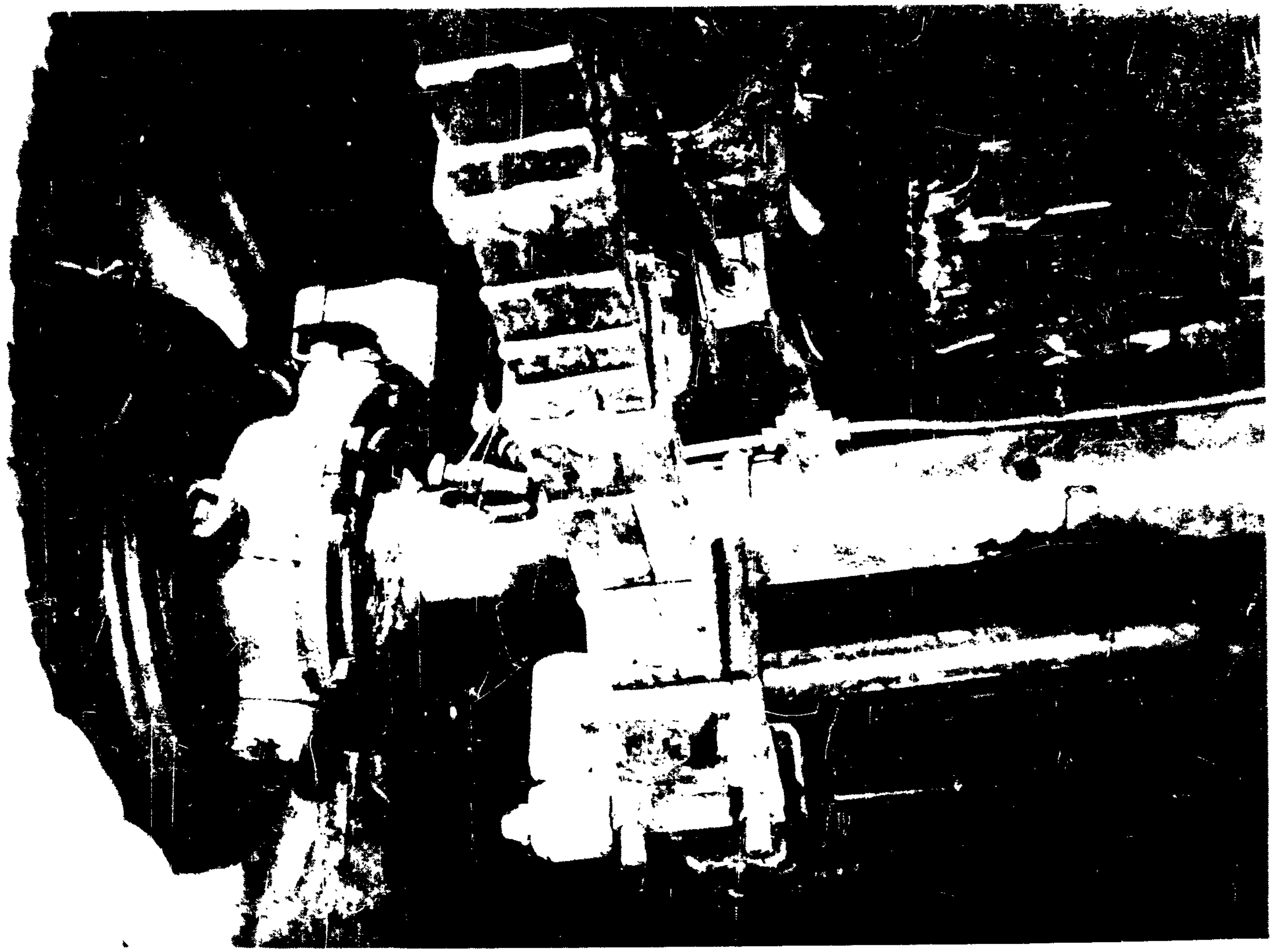


M-38-A1, CONDITION OF UNDERSIDE OF VEHICLE PRIOR TO ATMOSPHERIC EXPOSURE TESTS (M-38-A1 TEST VEHICLE)

FIGURE 67

M38A1. CONDITION OF UNDERSIDE OF VEHICLE AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 68

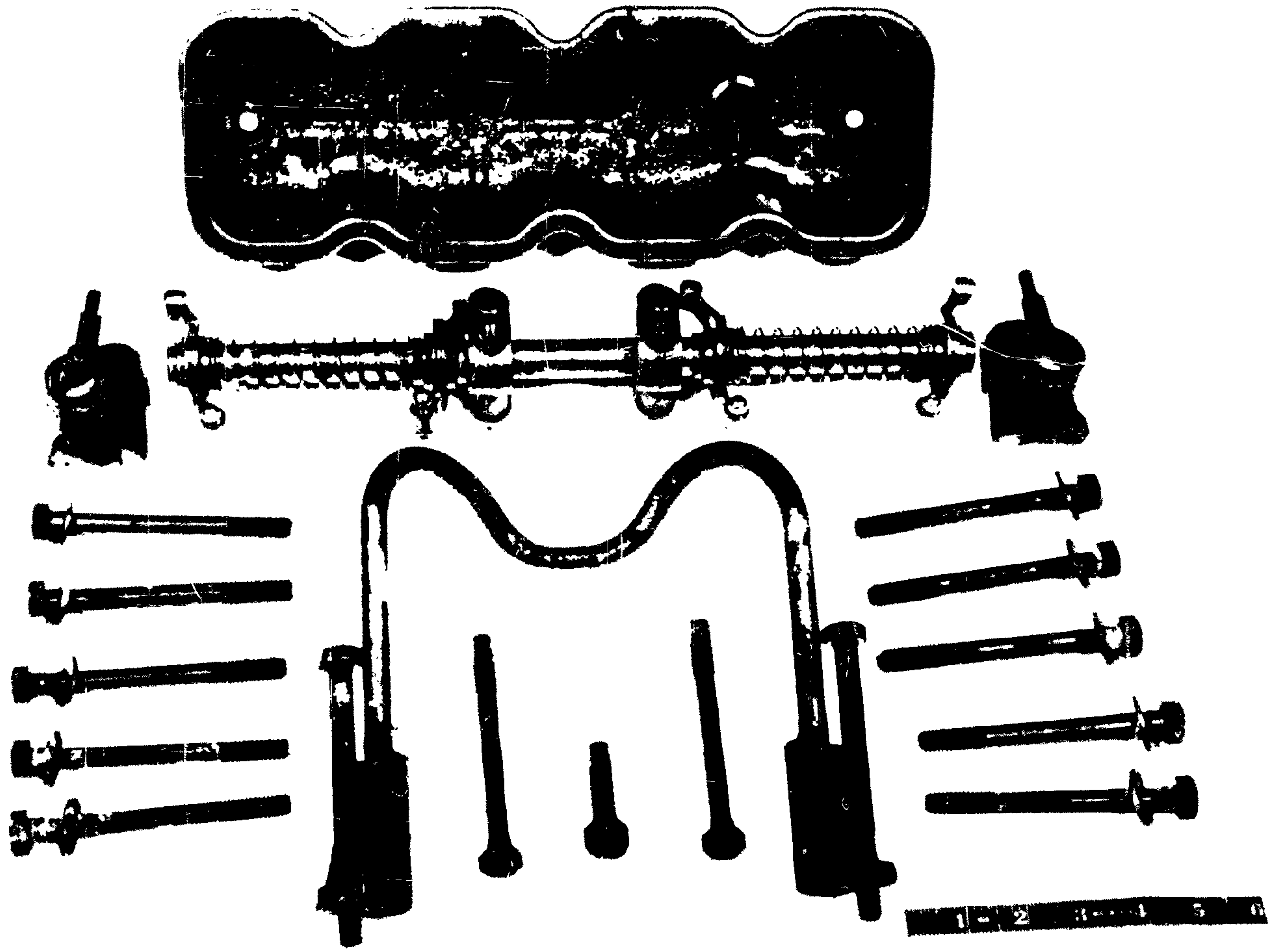


M38A1. CONDITION OF UNDERSIDE OF VEHICLE AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 69

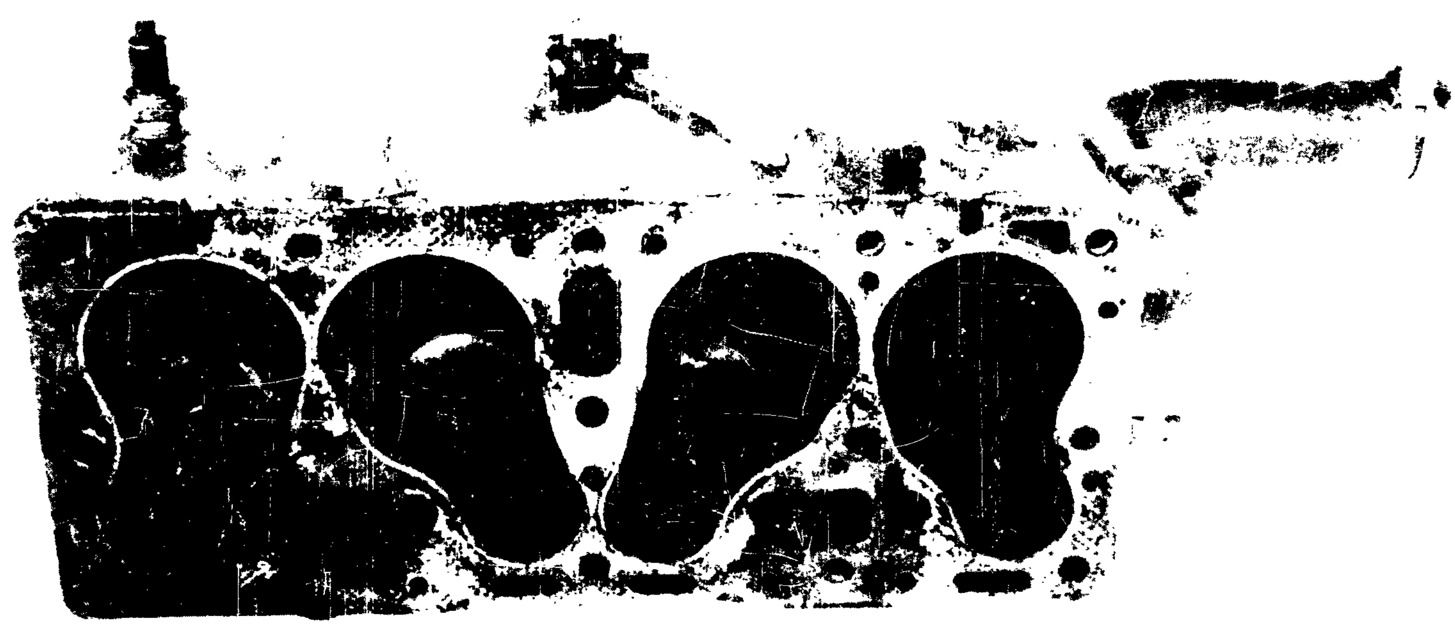
M38A1. CONDITION OF UNDERSIDE OF VEHICLE AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 70



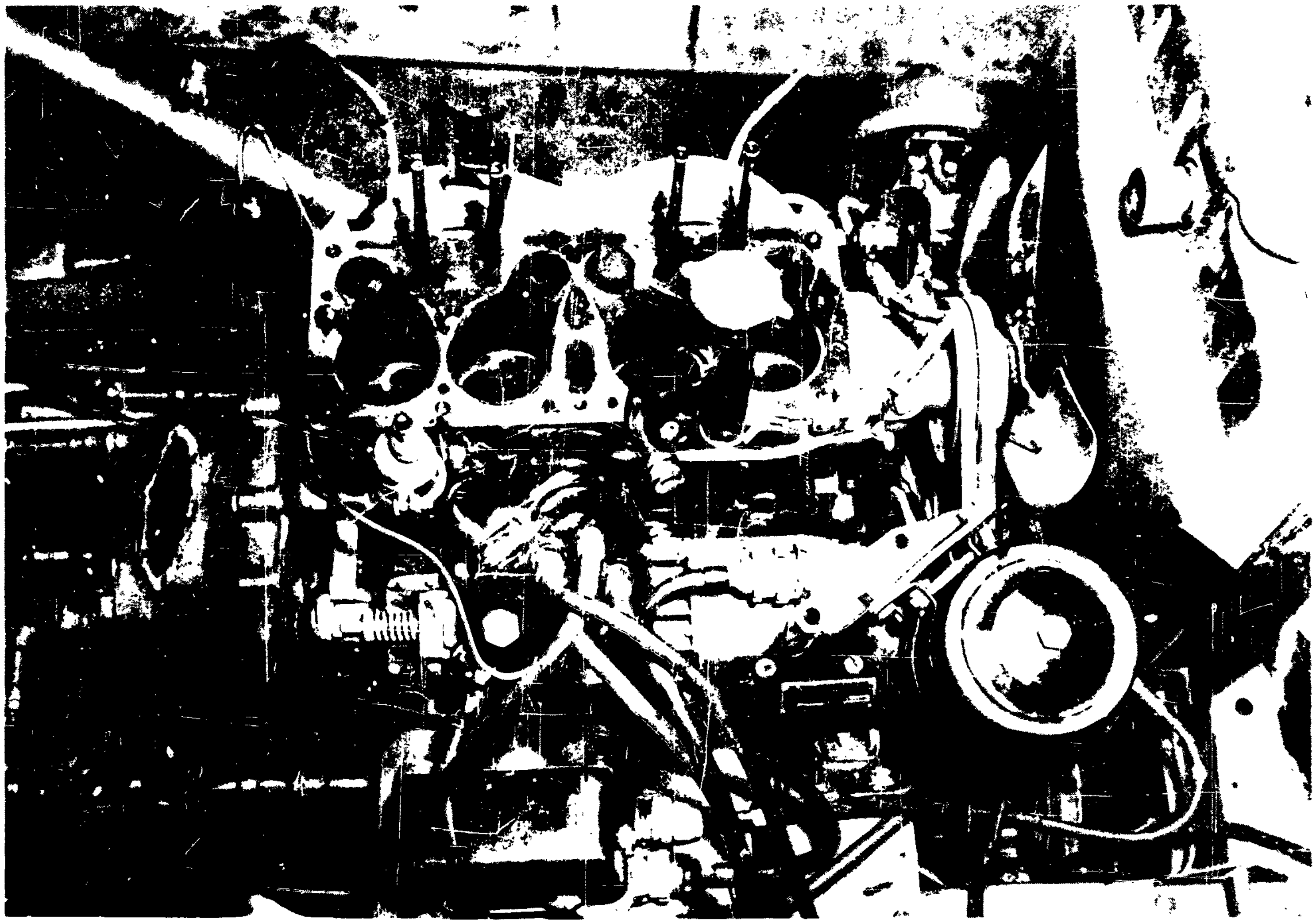
CATHODIC PROTECTION M38. TEST VEHICLE ENGINE ROCKER ARMS AND COVER WITH HOLD DOWN BOLTS

FIGURE 73



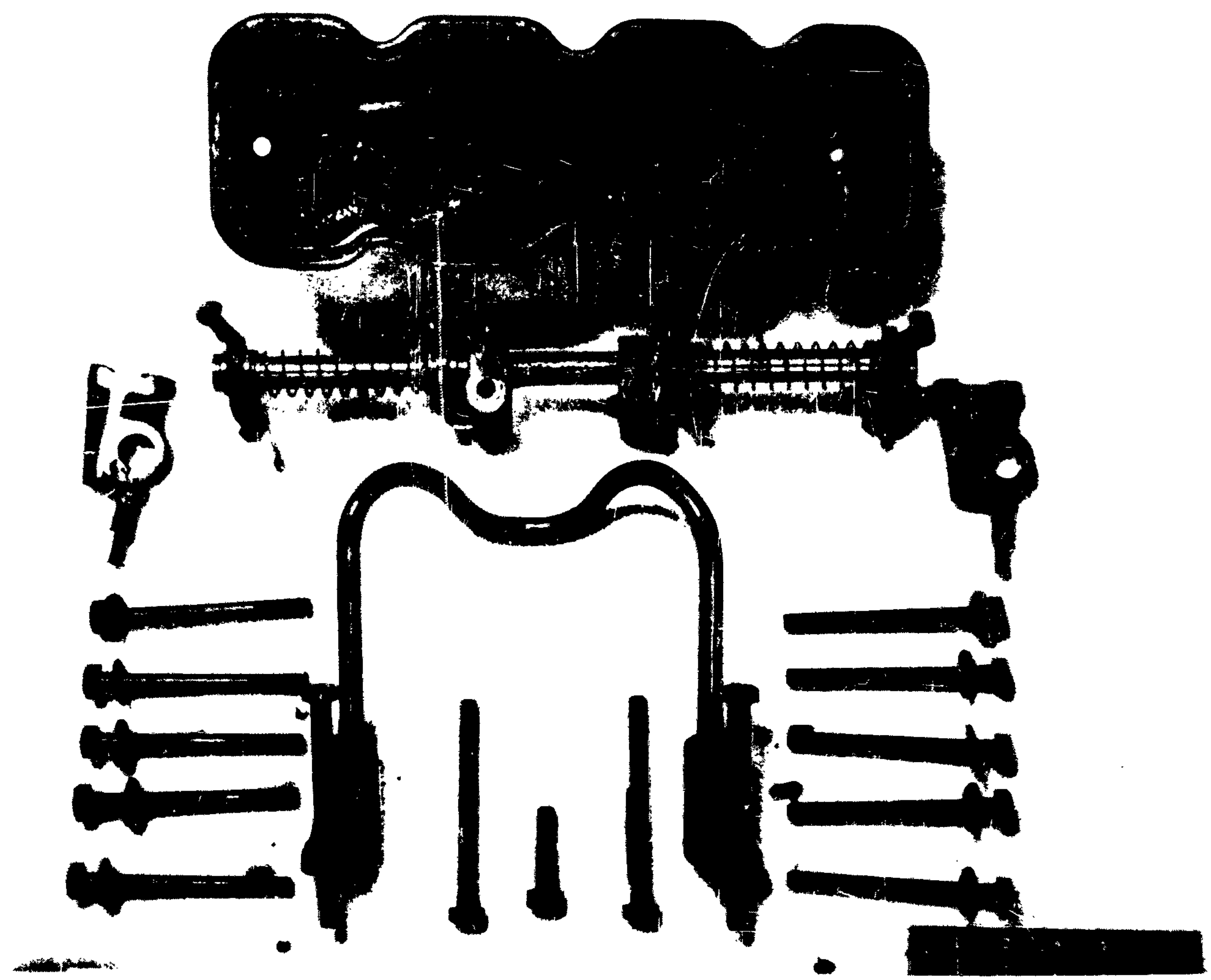
CATHODIC PROTECTION M38. TEST VEHICLE ENGINE HEAD

FIGURE 74



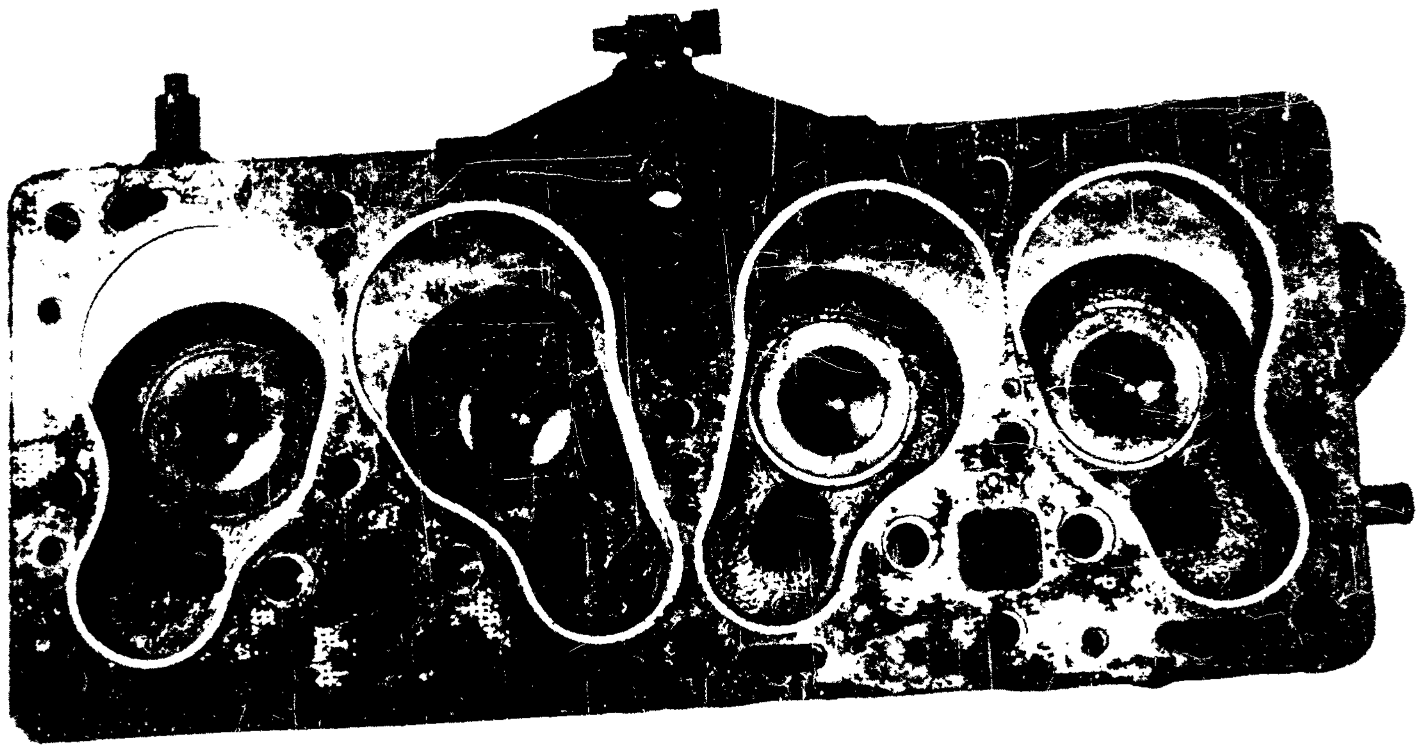
CATHODIC PROTECTION M38. M38 VEHICLE ENGINE

FIGURE 75



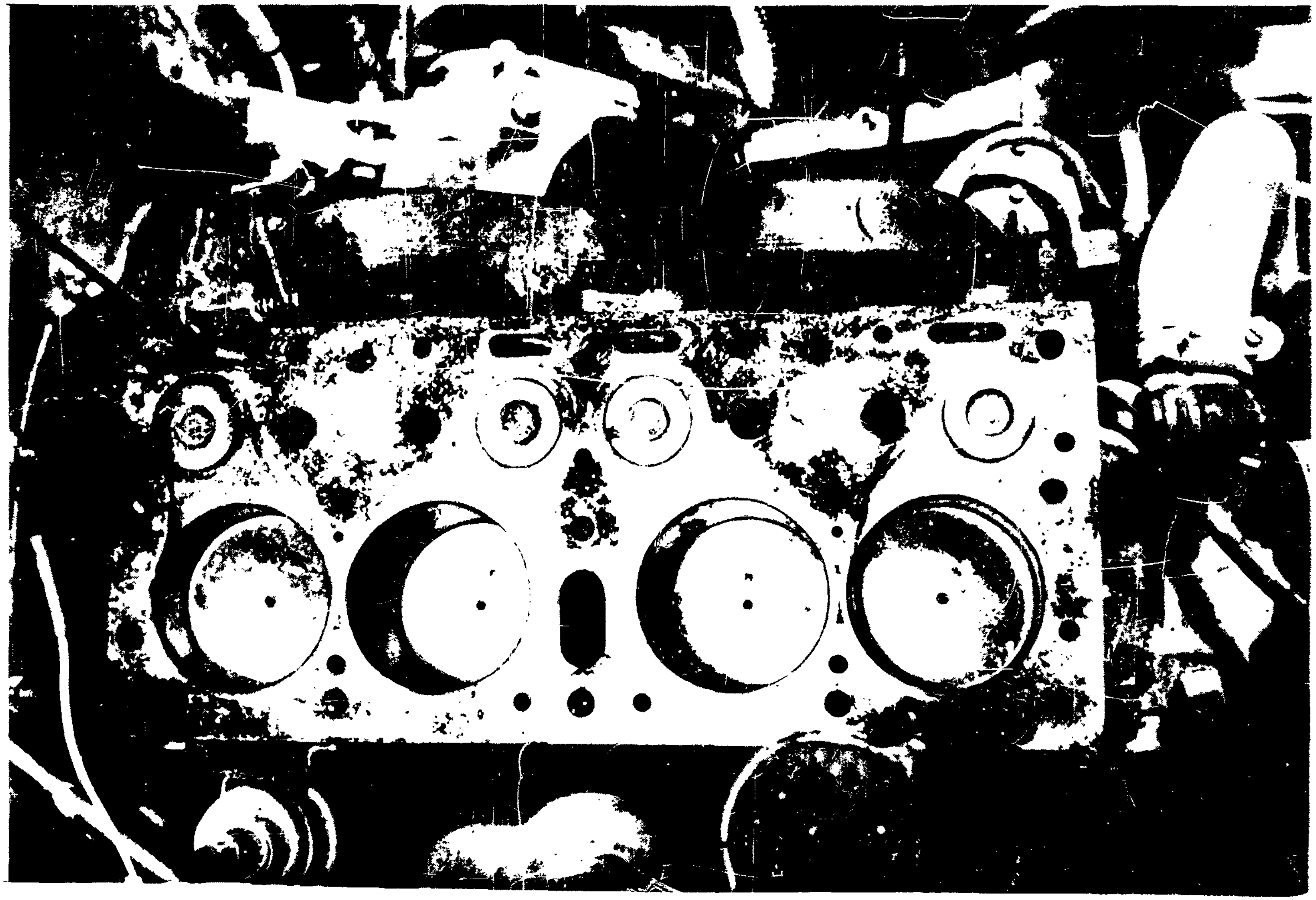
M38A1. CONDITION ENGINE ROCKER ARMS AND COVER AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 76



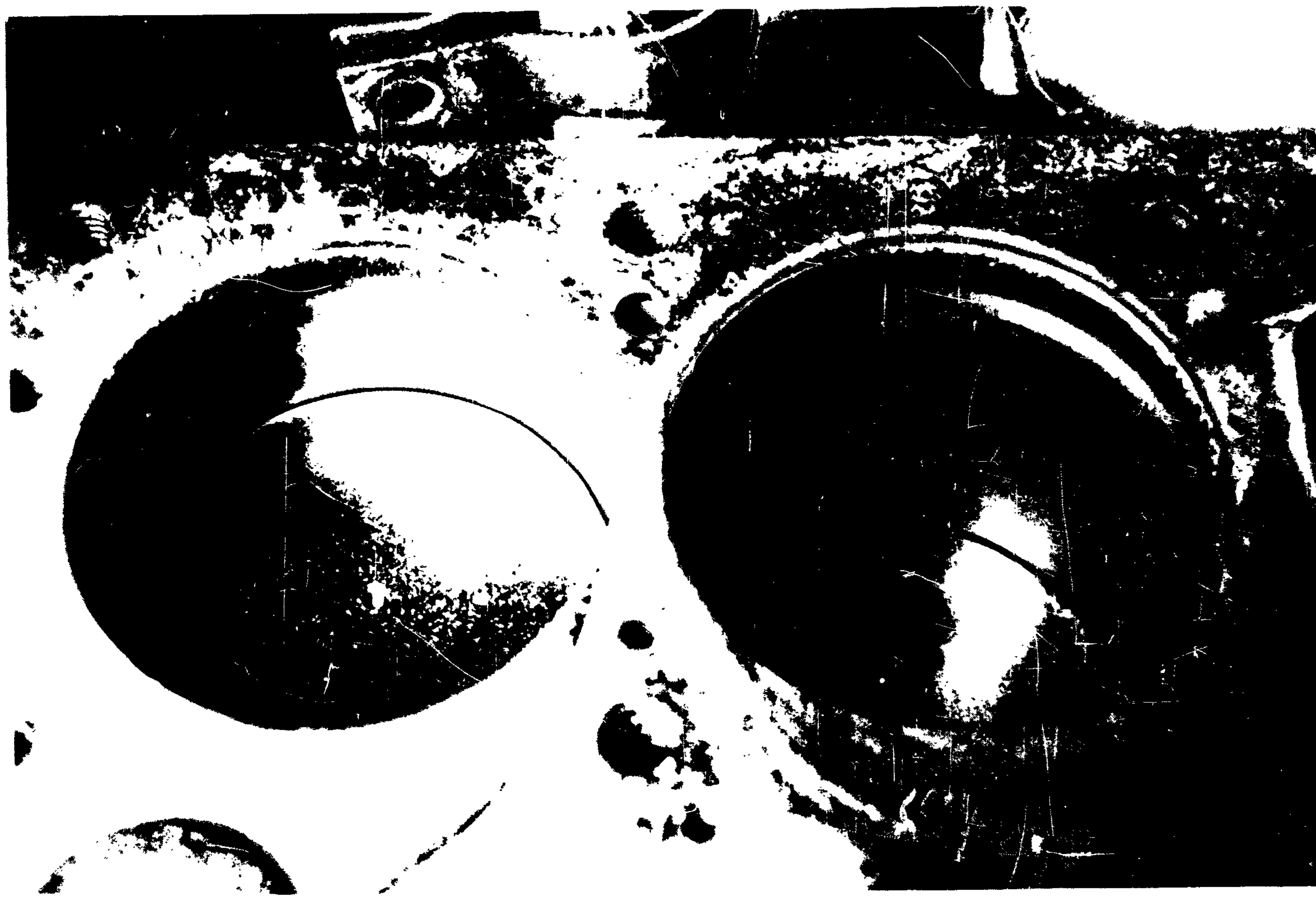
M38A1. CONDITION OF ENGINE HEAD AND VALUES AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 77



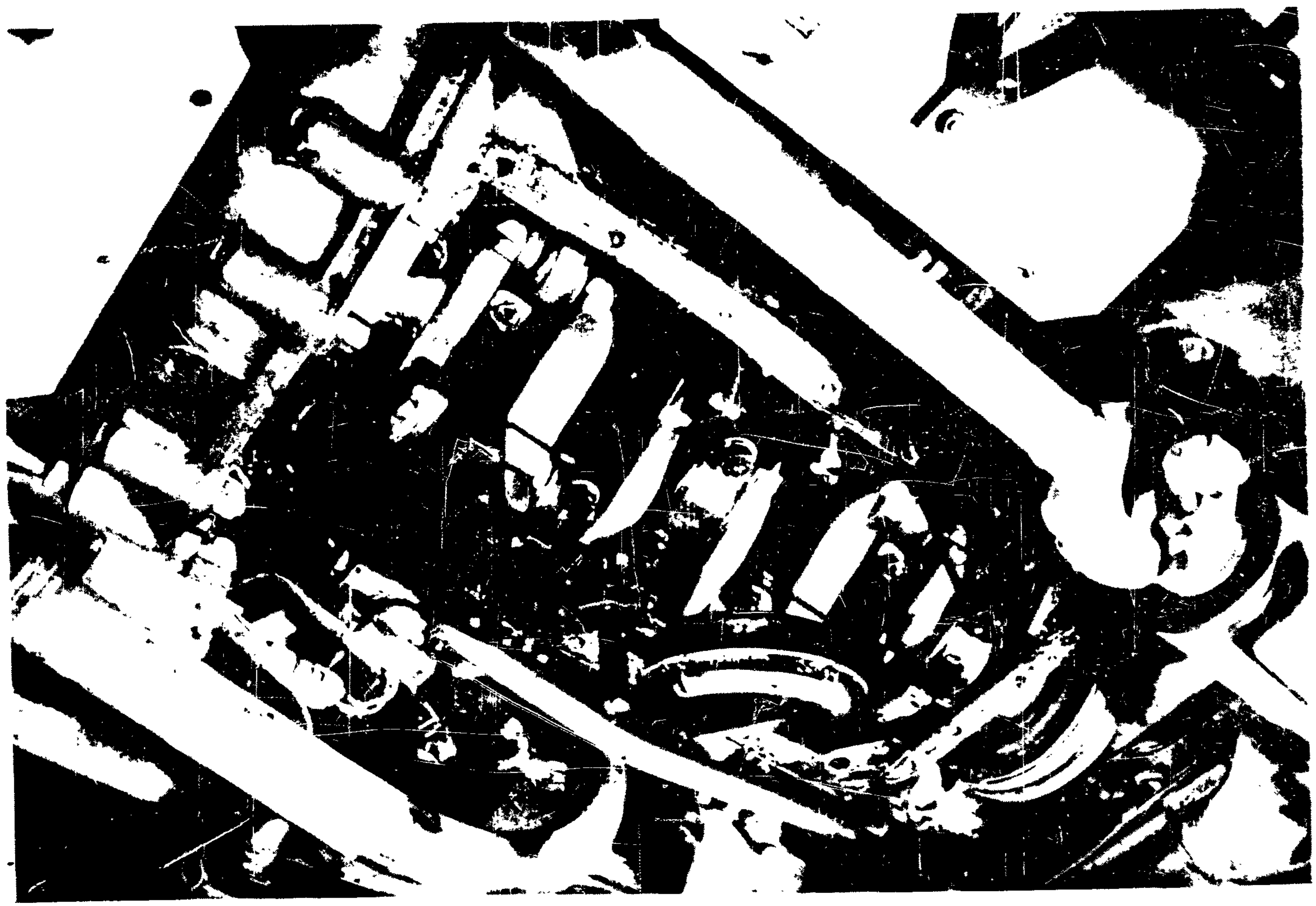
M38A1. CONDITION OF ENGINE AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 78



M38A1. CONDITION OF ENGINE CYLINDER WALLS AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 79



M38A1. CONDITION OF ENGINE AFTER 34 MONTHS ATMOSPHERIC EXPOSURE

FIGURE 80

BODY ITEM	PAINT SYSTEM	GENERAL CONDITION AT END OF TEST	PHOTOGRAPHIC EVIDENCE (Figure Numbers)
Hood, Outside	P	One electrode lost adhesion	53
Hood, Inside	P	Satisfactory	--
Front Fender, Outside	P	"	--
Front Fender, Underside	P	"	--
Right Body Panel	P	"	--
Dash Panel	P	Corrosion on Hinge	57
Left Rear Body Panel	P	Satisfactory	--
Right Rear Body Panel	P	Advanced corrosion in seam members. Loss of 2 Electrodes	48
Body Floor, Rear	P	Advanced corrosion in seam members	60
Battery Cover	N	Advanced corrosion over surface and along seams	50
Guard Assembly	N	Advanced corrosion over surface and along seams	55
Left Fender	N	Corrosion along masked edge	56
Cowl Panel	N	Satisfactory	--
Left Body Panel	N	Corrosion along seam	54
Main Front Floor	N	Satisfactory	--
Headlamp Assemblies Right & Left	O	Severe corrosion around lamp housings	52, 51
Windshield Frame	O	Corrosion around hinge area	34
Gasoline Filler Insert	O	Satisfactory	--
Rear Body Panel	O	Satisfactory	--
Front Bumper	O	Limited corrosion on surface	--

TABLE VI

PERFORMANCE OF PAINT SYSTEMS P, N, O, AND CORRELATION WITH PHOTOGRAPHIC DATA

Severe corrosion occured along seams and masked edge members of Systems P and O. (See Figure 56) Loss of paint adhesion and corrosion was confined in general to the edge area. This type of failure appeared to be due to a galvanic condition resulting from the lack of protecting voltages on edge and bearing members.

Several body parts which exhibited corrosion but were not classified strictly as a failure were:

AREA	REPRESENTATIVE FIGURE
Hinges	Fig 58
Lintles	Fig 41
Bolts & Nuts	Fig 42
Latches	Fig 59
Brackets	Fig 58

Three electrodes lost adhesion when excessive strain was placed on connecting wires. This resulted in the exposure of the base metal and subsequent corrosion of that area. (See Figure 53) This corrosion was confined in System P by the protecting voltage applied to that body member by another electrode. However, one electrode lost adhesion and "lifted" as a result of a faulty epoxy patch which allowed water to penetrate into the electrode seal.

Examination of a good electrode after 35 months exposure showed a tight electrical bond and good seal to the conductive coating.

Typical paint failures occurred in box members or along welded seam structures. Here, the corrosion originated within the seam and spread to surrounding areas; this results in loss of paint adhesion and progressive surface corrosion. See Figures 40 and 55.

Examination of Engine-Power Train After Exposure

The engine and power train were dismantled and examined after test. (See Figures 65 thru 80) The following components were found free of corrosion and were judged in excellent condition, or in the same condition as at the start of the test:

I Engine.

a. Cylinder head
b. Rocker shaft and cover plate
c. Distributor

d. Cylinder walls
e. Crankshaft
f. Main bearings

II Transmission, Differential and Transfer Case.

a. Gears

III Suspension and Steering.

a. Wheel bearings
b. Brake drum
c. Ball joint

The following vehicle components were considered defective or deteriorated as a result of the storage period:

I Radiator.

a. Coolant contaminated and radiator badly in need of cleaning

II Carburetor & Fuel Pump.

a. Rubber diaphragms defective. Carburetor and fuel pump required rebuilding.

III Instrument Cluster.

a. Ammeter defective. Required replacing.

Other rubber engine components, such as hose, gaskets, etc. appeared to be satisfactory and were not replaced.

The vehicle was subsequently placed in operation after repair of defective parts and run approximately 50 miles without trouble.

FINAL RESULTS:

Of nine major assemblies painted with the Type P System, four were found satisfactory after the exposure period. One was satisfactory, but lost an electrode. Two exhibited severe corrosion along seam or box members and one exhibited corrosion on a hinge area.

Of six assemblies painted with the Type N System (no protecting voltages), two were found satisfactory after the exposure period. Two exhibited advanced surface corrosion, one advanced seam corrosion, and one lost paint adhesion along a masked edge.

Of the one major and four minor areas painted with System O, two were found satisfactory after the exposure period. One exhibited severe surface corrosion, one limited surface corrosion, and one corrosion around a hinge area.

Corrosion failures as related to surface area under protection for the three systems are as follows:

AREA PROTECTED SQ. IN.	SYSTEM	ESTIMATED PERCENT OF TOTAL AREA EXHIBITING CORROSION
11,361	P	0.16%
4,248	N	0.24%
2,200	O	0.41%

THEORY:

Corrosion is the chemical combination of a metal with certain non-metals such as oxygen, nitrogen, sulfer, etc. It is characterized by a degradation of the metal and loss of its metallic properties. Since iron and its alloys are used extensively as structural and mechanical members in motor vehicles it is important to reduce the atmospheric corrosion of these metals especially, during long periods of outside storage.

Corrosion in iron occurs when the metal loses two electrons from each atom forming a ferrous compound.

$$Fe = Fe^{++} + 2e^-$$

$$\text{Iron} = \text{Ferrous Ions} + \text{electrons}$$

The metallic iron goes into solution as ferrous ions, and the metal takes a negative charge from the electrons which remain on it.

This results in the passage of an electric current from the metal into the electrolyte. Atmospheric corrosion of iron is possible thru the collection of moisture on metal surfaces from rain, etc., and the subsequent chemical reaction between the metal and gases entrapped in the moisture. In general, paints simply act as barriers between the metal they are to protect and an environmental electrolyte. Simple cells develope as porosity in the protective coating allows the electro-lyte come in contact with the metal.

Cathodic protection is then the reversal of the normal electron current flow from metal to positive metal ion. This is achieved in practice by making the item to be protected more negative with respect to a common anode thru an electrolyte. Protection can be achieved under most conditions of polarization and in the presence of sulfate-reducing bacteria.

The electrolyte must, however, be: (1) conductive to electrical current, and (2) able to supply ions in electrical chemical reactions. In electrolytic conduction, molecules are separated into two oppositely charged parts called ions. Although the dissociation of the molecule produces positive and negative ions, there is no tendency for them to move unless conduction takes place. By making the metal to be protected cathodic, or negative, the negative ions are then attracted toward the anode. This is a reverse of the normal ion flow produced in iron by the chemical corrosion process.

The electrolytic paint used in this test to impress a negative charge on the vehicle body exhibits the required characteristics of an electrolyte. It is conductive and supplies ions when dissociated electrically. The electrical characteristics of resistivity can be formulated to provide the desired current transfer. For example, a 2½ mil thick coating of the #R41 electrolytic paint affords a resistivity of approximately 4,500 ohm-cm. This corresponds to a soil electrolyte of silt loam. Sea water has a resistivity of about 100 ohm-cm.

The potential necessary to reverse the work function of normal corrosion has been found to be 0.8 to 0.85 volts. The current density to achieve complete protection has been found to be between 0.0064 and 0.96 milliamps per sq. inch of surface area. This corresponds to the average current density measured in Table IV for system "P" electrodes.

DISCUSSION:

The discussion will be limited to remarks on the electrolytic cathodic paint system.

Problems involved in completely removing the old paint from the vehicle body resulted in several areas where the electrolytic paint did not have good adhesion to the base metal. Lifting of the paint caused high resistance areas to form, and resulted in loss of protecting potentials in these locals. Similarily, bearing and impact areas which did not receive the anode coating exhibited an accelerated corrosion of the basis metal and subsequent loss of paint adhesion. It is therefore important that the electrolytic paint exhibit good adhesion to the base metal, and the anodic coating adhere tightly to the electrolytic paint.

Where the anode touches any part of the cathode a short developes. These shorts cause excessive power drain, and under some circumstances a power failure. Shorts in the system can sometimes be eliminated by discharging a capacitor into the shorted circuit. This in effect opens or "burns out" the immediate short, thus placing the circuit block in operation. Partial shorts are difficult to detect since it is not possible to actually measure the flux density of the system. That is, it is not known if all the power into a given electrode is being distributed to the cathode evenly. A low resistance area of a few square inches could easily have a flux density of several milliamps, thus reducing the distribution of the surrounding cathode to near zero.

CONCLUSIONS:

1. The electrolytic-cathodic paint system did not provide total protection from corrosion.

2. The electrolytic paint system did exhibit superior corrosion protection as compared to the conventional Ordnance paint system, "O", and the unprotected system "N".

3. The electrolytic paint system did not prevent chalking and fading of olive drab finish coat.

RECOMMENDATIONS:

It is recommended that future work on electrolyte paint systems study problems of (1) practical application and (2) theoretical functions of uniform current densities in thin conducting layers.

ACKNOWLEDGEMENTS:

The assistance of the Experimental Division of the Detroit Arsenal is acknowledged in their preparation and painting of the test vehicle.

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